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U.S. RESEARCH SAFETY VEHICLE (RSV) PHASE I PROGRAM- VOLUME I, INTRODUCTION AND EXECUTIVE SUMMARY

Contract No. DOT-HS-4-00841
June 1975
Final Report

PREPARED FOR:
U.S. DEPARTMENT OF TRANSPORTATION
NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION
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16. Abstract

Current passenger car usage patterns and factors influencing usage are analyzed and projections of usage patterns in the mid-1980's are made. Similarly, current available data on six categories of vehicle accidents are analyzed and projections made of national accident patterns in the mid-80's; the effect of potential reductions in these projections as a result of safety programs and other factors related to driving safety are estimated. (Volume II)

Based on the usage and accident projections, the characteristics of an RSV (weighing under 3,000 lbs C.W.) for operation in the mid-1980 traffic environment are described. (Volume III)

A recommended set of specifications for the RSV are developed considering the potential safety payoff accruing to an increased level of safety performance, the need for energy conservation, availability of material resources, and changes in vehicle mix. (Volume III)

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PREFACE

The Research Safety Vehicle (RSV) Phase I program was conducted by the Advanced Systems Laboratory (ASL), a division of AMF Incorporated, Goleta, California.

Since the Technical Report Documentation Page precludes the identification of authors with their respective areas of responsibility, recognition of their contributions is indicated. The principal program investigators from AMF/ASL's technical staff conducted studies in the following subject areas:

J. Andon - Lighting, Signaling, Power Plants, and Accessories.

Dr. A. V. Khadilkar - Riding and Handling Systems.

R. W. Olson - Cost/Benefit Methodology.

L. S. Pauls - Crashworthiness and Occupant Protection.

The conduct of the overall program was under the direction of W. J. Rup.

In a program of this significance, requiring a multi-disciplinary approach, additional technical support and assistance was required to supplement the capabilities of the ASL staff. Members of General Research Corporation, Santa Barbara, California, headed by Dr. E. Dodson, analyzed current passenger car usage and vehicle accident patterns, and made the projections of these patterns for the mid-1980 period.

A vital element in reconstructing the national accident patterns in the detail desired for an adequate foundation for program definition is the acquisition of appropriate and relevant statistical data. In this task, the assistance and cooperation of Ms. Barbara Brown and Mr. James O'Day, Highway Safety Research Institute, The University of Michigan, and Messrs. Eugene Lunn and Reuben Harding, Office of Statistics and Analysis, NHTSA/DOT, is gratefully acknowledged.

Mr. Daniel Hirsch, Contract Technical Monitor of AMF/ASL's program and Mr. Edward Chandler, Group Head, RSV Group, Office of Vehicle Safety Research, NHTSA/DOT, are commended for their objective conduct and assistance in all aspects of their monitoring and program support functions.

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Section 1
INTRODUCTION

The phased structuring of the Research Safety Vehicle (RSV) program represents a rational, systematic approach in passenger car research and development whereby each program phase has definitive objectives; the accomplishment of each phase objective provides a firm basis for initiating its successor phase.

As currently structured, the RSV program is comprised of four separate and distinct phases having the following objectives:

- Phase I, Program Definition.

This initial and vital phase has three basic objectives: (1) project the probable usage and accident environments to be encountered by the RSV in the mid-1980's; these projections to be based on analyses of recent national trends in passenger car usage and accident environments; (2) characterize RSV concepts that would be appropriate for operation in the projected environments; and (3) recommend safety performance specifications for an RSV which have the maximum potential payoff in reducing accident fatalities and injuries in the mid-80's.

- Phase II, RSV Development.

The basic objective of the second phase is the development of the final designs of an RSV that conform with the safety performance specification. The design development involves engineering analyses and testing to demonstrate the feasible levels of performance that can be attained with producible, cost effective designs.

The current national problems with energy self-sufficiency and the economy have long-term implications for the automobile industry. The most significant implication is that unlimited, low cost energy will no

longer be available to any industrial segment in the United States. For the RSV program, this is reflected in NHTSA's expressed position that a 30 mpg fuel economy goal is equal to the 50 mph crashworthiness goal. The unprecedented status of domestic energy resources and the accompanying effect on the economy requires caution in the use of historical trends through 1973-74 as indicators of trends in the next decade. Therefore, another necessary objective of Phase II is to monitor changes in those external factors that may influence future vehicle usage and accident environments and conduct the required updating of Phase I findings to assure that the evolving RSV designs reflect mid-80 projections.

- Phase III, Prototype RSV.

  This phase has the objective of further refinement and optimization of the Phase II designs and the subsequent fabrication, assembly, and checkout of the prototype RSV(s).

- Phase IV, RSV Test and Evaluation.

  In the final phase, the prototype RSV(s) are tested and evaluated by an independent test conductor to demonstrate its conformance with performance specifications and applicability for use in the projected operational environments.

This report presents the findings of the Phase I Program Definition studies conducted by the Advanced Systems Laboratory (ASL), a division of AMF Incorporated, for DOT/National Highway Traffic Safety Administration under Contract No. DOT-HS-4-00841. The studies began with the effective date of the contract, January 18, 1974. Interim and supplementary reports on usage and accident projections and RSV characterization were issued in September and October 1974 respectively. An interim report on the recommended RSV safety performance specifications was issued in December 1974. The specifications, revised and updated to reflect the results of recent preliminary design studies, are presented in this final report.

The AMF/ASL final report on the Phase I studies is presented in three volumes; a description of the contents of each volume is as follows:

- Volume I, Introduction and Executive Summary

The introductory section provides an overview of the RSV program and the specific considerations addressed in Phase I. The executive summary contains comprehensive condensations of (1) the usage and accident environments projected for the mid-1980's; (2) the estimates of the societal costs associated with various projected accident categories and cost/benefit analysis methods; (3) the characteristics of two RSV concepts appropriate to the projected environments; and (4) the recommended RSV performance specifications.

- Volume II, Program Definition Foundation

This volume presents the detailed study findings of the accident and usage projections, societal cost estimates and techniques for conducting cost/benefit analyses. The projections are discussed in terms of data sources, data quality and limitations, projection methods, influence factors affecting projections, and the projected usage and accident data. Societal costs estimates are presented for six categories of accidents involving vehicles; accident categories are ranked in the order of potential payoffs with appropriate vehicle performance specifications. A cost/benefit methodology is presented for evaluating various levels of safety performance.

- Volume III, RSV Characterization and Performance Specifications

The first section in this volume presents the characterization descriptors of the two RSV concepts appropriate for operation in the projected mid-1980's traffic environments and the rationale supporting the characterizations. The second section presents the recommended RSV performance specifications and a discussion of the supporting data and considerations for each specified requirement. Comparisons are made between this specification and the DOT/NHTSA guideline specification for the U.S. Intermediate ESV, dated February 16, 1973.

SECTION 2
EXECUTIVE SUMMARY

2.1 SCOPE OF SUMMARY

The executive summary presents comprehensive condensations of the essential findings of the program definition for the Research Safety Vehicle (RSV). Program definition is comprised of three basic studies: (1) usage and accident projections of the traffic environment in the mid-1980's and estimates of the societal costs incurred as a consequence of the projected accident profiles, (2) the characterization of RSV concepts operating in the projected environment, and (3) the recommended safety performance specifications for an RSV which have the maximum potential payoff in reducing the societal costs of the projected accident environment.

In developing this program definition for an RSV, recognition is given to the need for conserving energy and material resources, for preserving environmental air quality, and for providing an economical vehicle for private transportation. These considerations are reflected in the recommended performance specification where requirements appropriate to these considerations are addressed.

The summary is organized in the same topical order as is the detailed body of the final report contained in Volumes II and III. Data and rationale supporting the summary presentations are held to a minimum and to the essential or significant findings in order to preserve the desired conciseness of this section; descriptions of procedural methods, techniques, and source references, used in developing the summarized findings are purposely omitted.

2.2 TRANSPORTATION USAGE PROJECTIONS

2.2.1 Introduction

Future transportation usage involves numerous considerations of both the demand for transportation and the availability of economic resources, fuel, vehicles, alternative modes of transportation, etc. Many of these are especially difficult to forecast at this particular time. However, it should be noted that, to a large degree, these considerations do not have a profound impact upon the overall usage picture in the mid-1980's. The total traffic environment is largely determined by overall economic and social factors which can be projected with reasonable confidence, i.e., most of the indicated elements of change and uncertainty represent minor perturbations of these overall influences. For example, there is considerable uncertainty about future bith rates. Thus, future family size is difficult to forecast with the consequent uncertainty about demand for large family cars in the mid-1980's. However, the overall traffic environment will be largely determined by the size of the mid-80's driving population, all of whom have already been born, and thus can be projected to 1985 with confidence.

The first step in the general approach to forecasting is to identify the salient factors which bear upon future transportation usage. A major part of this investigation is a review of historical trends and patterns, carried out at a sufficient level of detail to discern key individual elements within this overall pattern of usage. Then, current and future developments and other factors which bear upon the likely continuation of these trends are considered.

When there is a basic rationale underlying observed historical trends, and there are no current and future developments which indicate changes from past trends, forecasting can be carried out using mathematical techniques of regression analysis. These techniques result in mathematical equations, or models, which provide an apparent rigor and quantitative

"force" to forecasts. In this study, it was found that, in general, there are strong arguments against the use of these conventional mathematical techniques of time-series projections. Among the points mitigating against direct mathematical projections of transportation usage from historical data are the following:

- There have been great variations in birth rates, resulting in distinct differences in the size of particular age groups. As these groups progress through the age cycle, there are various disproportionate impacts upon future transportation usage.
- Historical patterns do not reflect effects of recent and pending changes in fuel costs, auto safety and air quality standards, the annual rate of inflation, housing patterns, and other factors.
- Very recent shifts in such factors as small car purchases and in percent of women who drive can be expected to reach saturation levels in the near future, i.e., they cannot be simply extrapolated.

The differences among age groups is considered fundamental in this study, and virtually all projections are made in sufficient detail to account for them. The various changes and saturation levels noted above, and others noted throughout the study, can only be appraised judgmentally. There is no purely objective, mathematical method of forecasting, say, future fuel prices and their impact on usage.

2.2.2 Population and Household Characteristics

Population of Driving Age. The size and age structure of the United States' driver population in 1985 is closely related to the historic birth profile which is noteworthy for: (1) an unusually low level of births

during the depression/World War II years [1929-1945], (2) the post-war "baby boom", and (3) an unexpected sharp decline in births subsequent to 1970.

Immigration, the other factor affecting the nation's population age structure, is regulated by legislation, and does not materially alter the key variations noted in the birth profile.

As these key variations in birth trends progress through the age cycle, they appear as marked shifts in population patterns which, in turn, will have wide-ranging effects upon future transportation usage.

If one considers all persons over 15 years of age, representing the great preponderance of potential drivers, an increase of over 22 million (or over 14%) in this overall age group by 1985 will be experienced. It should be noted that projections to 1985 of those 15 and older are based upon births already recorded.

However, as indicated in Table 2-1, the bulk of this increase will be in the 25-44 age brackets, a group characterized by higher income production and increased transportation usage. In this period, the number of younger people (those under 24) actually declines as does the group born in the depression, i.e., those in the 45-55 age group, a group characterized by peak income and multi-car ownership.

Because of the marked differences in automobile purchases and usage (and accident rates) by the various age groups, these shifts in age structure preclude simple aggregate extrapolation of existing trends. Therefore, this study has been concerned primarily with specific age groups. The number and age of potential drivers, size of household, household income, and age of household head have been examined as factors to be considered in predicting transportation usage in the mid-1980's.

Table 2-1

U.S. Population Projections by Age Groups (in thousands)*

Year	Age Groups							
	15-19	20-24	25-34	35-44	45-54	55-64	65-74	75 & Over
1974	20727	18968	29884	22670	23651	19580	13317	8407
1975	20943	19404	31114	22721	23563	19867	13549	8621
1976	21048	19800	32390	22937	23404	20143	13748	8798
1977	20959	20227	33529	23413	23137	20446	14010	8906
1978	20843	20583	34510	24127	22905	20667	14239	9059
1979	20649	20851	35652	24812	22631	20882	14460	9211
1980	20221	21067	36962	25370	22406	21083	14680	9371
1981	19651	21172	38326	26125	22225	21249	14875	9521
1982	19042	21085	38828	27452	22058	21375	15060	9659
1983	18376	20971	39544	28692	21965	21458	15242	9825
1984	17875	20780	40193	29941	21976	21434	15468	9992
1985	17668	20355	40841	31150	22036	21366	15725	10199

*Population estimates by age groups were extracted from Current Population Reports Series P-25, No. 493, which includes Armed Forces abroad and net immigration of 400,000 persons each year.

Driving Population. In examining past trends, the proportion of licensed drivers has increased in all age groups, with the increase in the proportions of female drivers particularly evident. When considering the availability of driver education and increases in numbers of women entering the work force, these proportions will continue to increase. Also, as women drivers progress through the age groups, they will increase the proportions in the older age groups by replacing those who never learned to drive.

In order to forecast the driver proportions by age and sex that could reasonably be expected in 1985, past and present driver distributions were analyzed, together with licensing limitations for the youngest age group, saturation limits among the intermediate groups, and a decline in physical capability as well as economic status after age 55. Also considered was the large number of females who live past normal driving age. These factors were combined using engineering judgment to derive the driver distribution by age and six in the projected 1985 population projections shown in Table 2-2.

Household Characteristics. Automobile ownership patterns and travel patterns are highly dependent upon certain household characteristics including income, age of household head and size of household.

Historically, the total number of U.S. households has been increasing, reflecting population growth and more recently, changes in social patterns affecting the composition and structure of families. In particular, the trend toward smaller families and one person households will be reflected in an increase in the growth of the total number of U.S. households.

The average household size in the U.S. has been experiencing a steady decline. Recently, this decline has steepened due to low birth rates, increased divorce rates, and to the rapidly increasing number of one person households. The Bureau of Census estimates of household characteristics for March 1973 are as follows:

Table 2-2

Projected 1985 Driver Distribution

Age	Population (10^3)			Driver Population (10^3)			% of Drivers	
	Male	Female	Total	Male	Female	Total	Male	Female
16-19	7,125	6,886	14,011	5,344	4,269	9,613	75	62
20-24	10,305	10,049	20,354	9,738	8,340	18,078	94.5	83
25-29	10,688	10,515	21,203	10,154	9,043	19,197	95	86
30-34	9,852	9,786	19,638	9,359	8,416	17,775	95	86
35-39	8,661	8,748	17,409	8,228	7,611	15,839	95	87
40-44	6,748	6,993	13,741	6,411	5,944	12,355	95	85
45-54	10,630	11,407	22,037	10,098	9,582	19,680	95	84
55-64	9,874	11,492	21,366	9,088	8,964	18,052	92	78
65 & over	10,386	15,537	25,923	7,478	9,012	16,490	72	58
TOTALS	84,269	91,413	175,682	75,898	71,181	147,079	90.07	77.87

Source: Current Population Reports, P-25, No. 493. Population projections include Armed Forces abroad.

Characteristics of Households by Type: (in thousands)

Size of Household		Age of Head	
1 person	12,635	Under 25 years	5,476
2 persons	20,632	25 to 29 years	7,116
3 persons	11,804	30 to 34 years	6,447
4 persons	10,739	35 to 44 years	11,721
5 persons	6,426	45 to 54 years	12,805
6 persons	3,245	55 to 64 years	11,212
7 persons or more	2,769	65 to 74 years	8,369
		75 years and over	5,104
TOTAL	68,251	ALL HOUSEHOLDS	68,251

The decline in larger households during the last decade is readily apparent, as is the increase in one person households. A continuation of these trends is forecasted, i.e., that the proportion of large families will continue to decline and the percentage of one person households will continue to grow as the peak of the "baby boom" children enter adulthood and as the number of older persons (widows, widowers, etc.) increase. By extending past and present trends in household formation, and considering the effects of marriage, divorce and birth rates, the following number of household by size and age of household head are predicted for 1985:

Projected 1985 Characteristics of Household by Type: (in thousands)

Size of Household		Age of Head	
1 person	21,534	Under 25 years	7,328
2 persons	30,763	25 to 29 years	10,389
3 persons	17,139	30 to 34 years	10,409
4 persons	10,547	35 to 44 years	17,444
5 persons or more	7,910	45 to 54 years	12,561
		55 to 64 years	12,606
		65 to 74 years	10,221
		75 years and over	6,935
TOTAL	87,893	ALL HOUSEHOLDS	87,893

Not all the population is represented in households. Approximately 1.5% of the nation's driver population resides in "group quarters", i.e., college dormitories, military barracks, etc., and therefore are not included in household information. Practically all of these persons are in the under 25 age group and their car ownership and travel patterns are included in that group's predicted transportation usage.

Car Per Household Ratio. As the number of household formations increases and the average household size continues to decrease, the present trend in ratio of cars per household will decline. This ratio has steadily increased from 1950 until recently when the rate of increase has slowed considerably.

It is expected that the car per household factor will continue its present modest rate of increase until the late 1970's because each year, larger number of "baby boom" children reach driving age while residing in their family household. By 1980, these children, for the most part, will have left their family households and will have established other household arrangements, thereby effecting the decline in the car per household ratio shown in Figure 2-1.

The number of households and the car per household ratio is one factor influencing future car usage. In the next sections other factors are considered and then integrated to form a final projection of usage.

2.2.3 Economic Factors

Among the key influences upon future transportation demand are basic economic considerations, a major determinant of usage. Transportation has long been recognized as a vital element of the nation's overall economy, and analysts have explored at length the direct relationships between aggregate economic activity and the demand for transportation service.

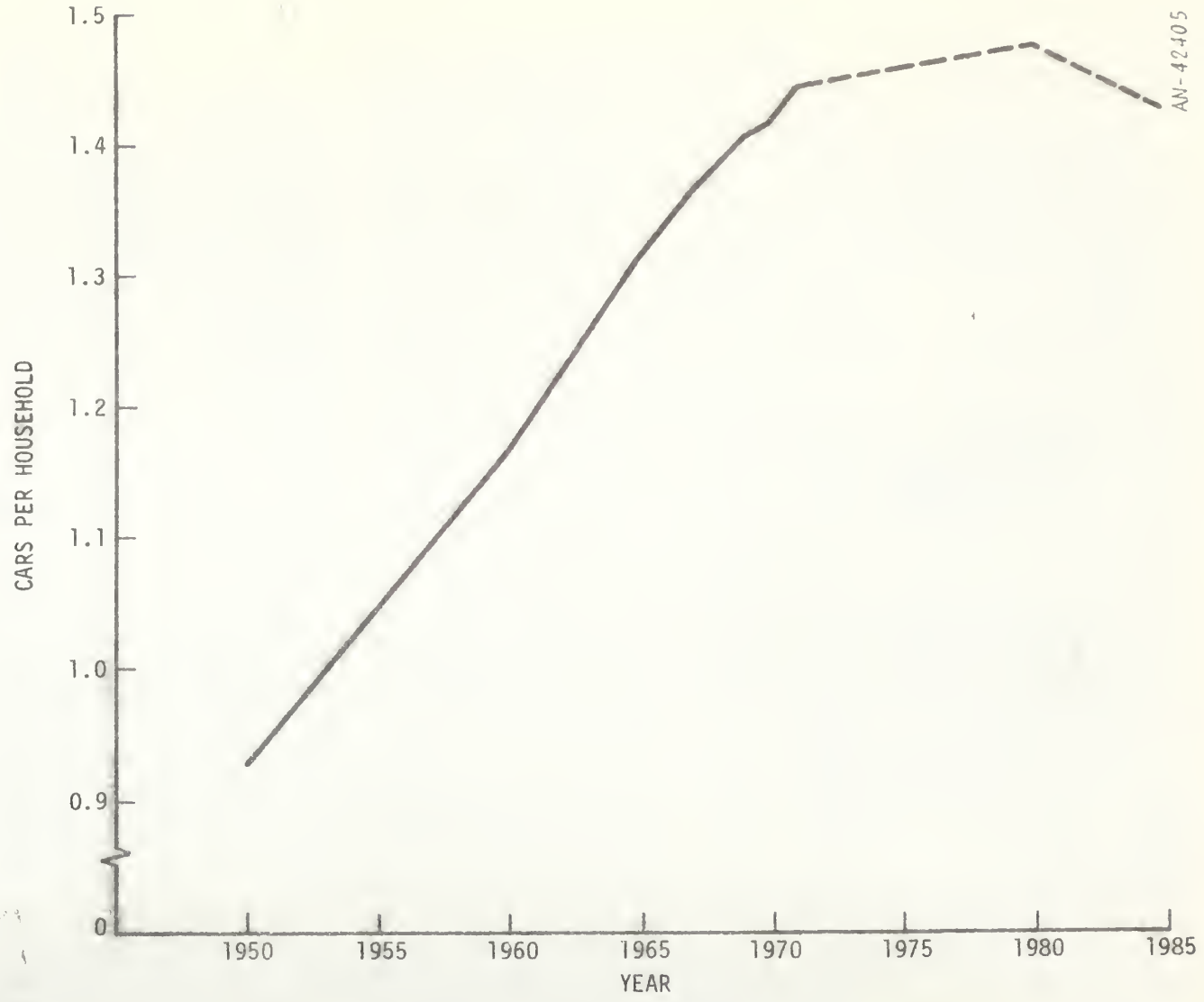


Figure 2-1. Cars per Household, 1950-1985

The forecasting of national economic trends is a complex undertaking where unpredictable political events can significantly alter annual forecasts of the national economy as evidenced by the current "double digit" inflation in the U.S. However, most of the variability in Gross National Product (GNP), the primary measure of aggregate economic activity, is in the government and private capital investment sectors. Personal consumption expenditures, the sector of most immediate interest for this study, has been much more stable over time, and is inherently more predictable (see Figure 2-2).

The shifts in age structure noted in Section 2.2.2 will result in a larger proportion of working age people within the nation's population, and will cause per capita income to increase. This, when coupled with the decline in birth rate (which will allow more wives to participate in the work force and lower the ratio of dependents to workers) will result in larger percentages of income available for discretionary purposes, i.e., for expenditures beyond basic food, clothing and household needs. Even if a relatively high rate of inflation persists, it is anticipated that growth in discretionary income, when measured in constant dollars, will allow a continuance of growth in consumer demand for goods and services.

Within personal consumption are expenditures for consumer durables (such as refrigerators, autos, etc.). These exhibit some short-term variability, as shown in Figure 2-3, but still can be extrapolated with reasonable confidence based on long-term trends.

From Figures 2-2 and 2-3, it can be seen that consumer durable expenditures represent an increasing share of total personal consumption outlays. A major portion of consumer durable expenditures is for automobiles and automobile parts. These data show some year-to-year instability, which is common to many durable expenditures. The purchase of a car can be readily postponed; however, over a period of a few years, the sale will generally be realized since the personal car is a need for a significant part of the population which depends on it as the only available transportation means.

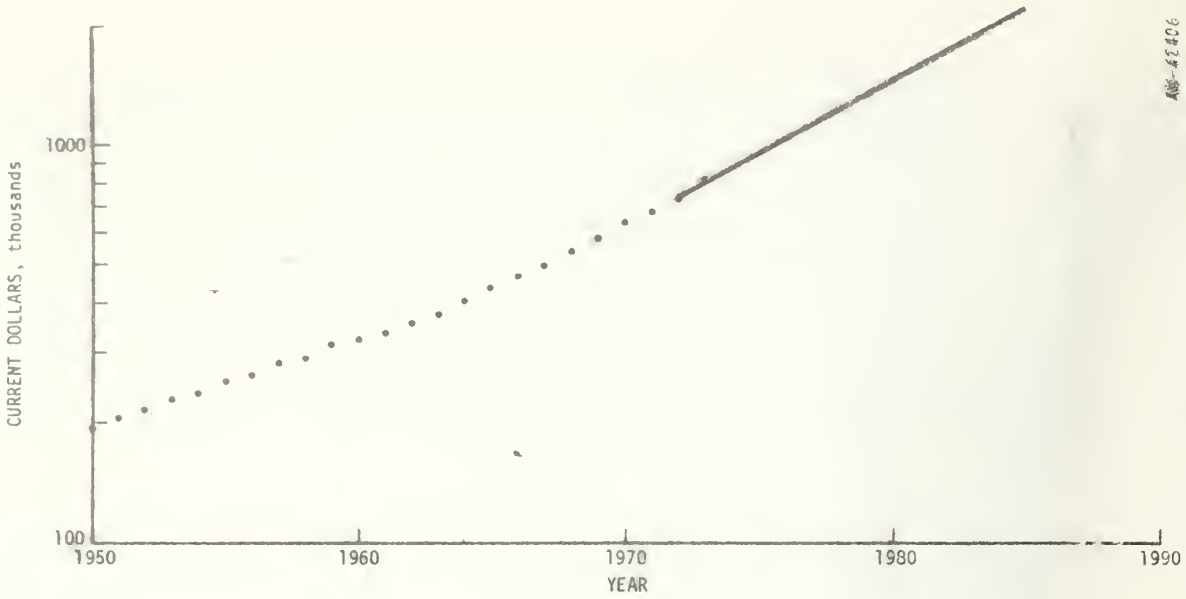


Figure 2-2. Personal Consumption Expenditures

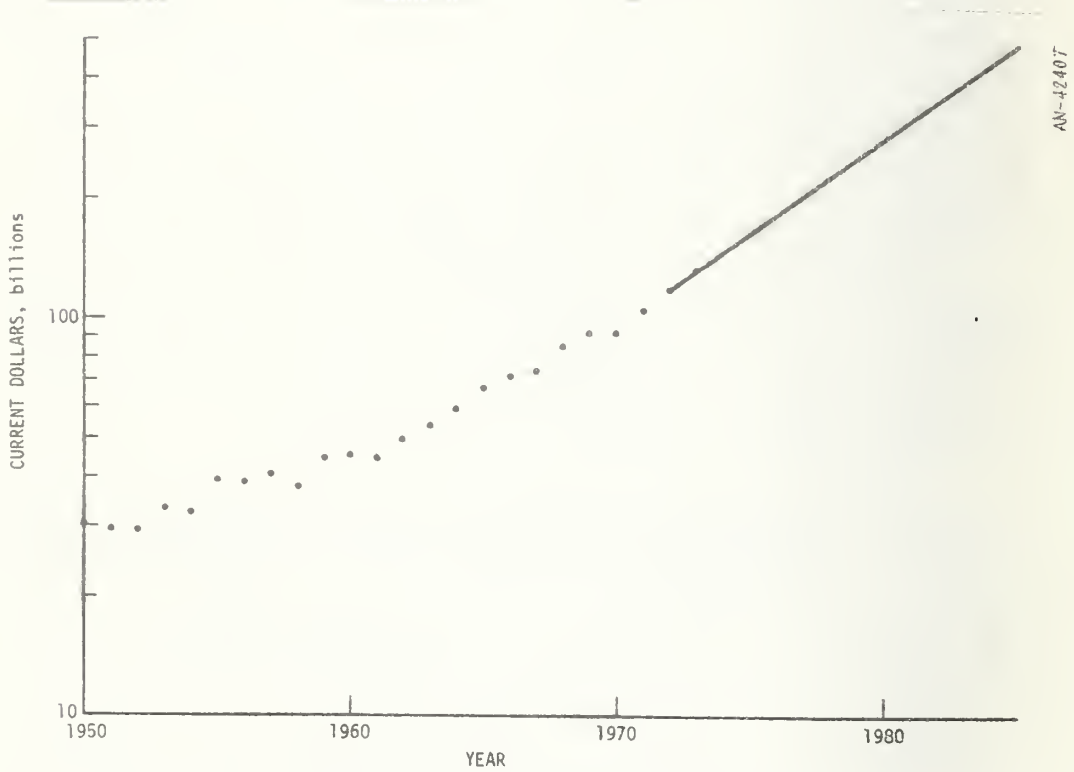


Figure 2-3. Expenditures for Consumer Durables

Because of recent inflationary price increases and higher fuel costs, some decrease in the rate of increase of expenditures for automobiles and parts is expected which will alter the recent trends up to 1973. However, it is anticipated that current inflationary impacts will not extend to 1985 because of federally instituted programs and policies to be taken as counteractions.

2.2.4 Transportation Factors

The preceding discussions of demographic and economic factors have been primarily concerned with the demand for automobile transportation. In this section, various transportation factors bearing upon both supply and demand are considered. Governmental projections of the future highway and roadway system are discussed first. While some reductions in the projected highway programs are foreseen, these are not considered sufficient to be a significant constraint upon growth of transportation usage. A second discussion focuses upon modes of transportation which represent alternatives to the automobile. Prospective changes in the relative use of these modes are almost exclusively in urban areas. While the federal government is sponsoring numerous development and demonstration programs for new urban transit systems, it is felt that these will have little effect upon automobile usage in 1985.

Consideration is also given to other transportation-related considerations, i.e., gasoline prices, air quality standards.

The Future Highway Network. In its 1972 National Highway Needs study, the Federal Highway Administration (FHWA) has compiled and integrated state studies with regard to their present and future highway transportation needs. This FHWA report contains an extensive description of the current and projected U.S. highway system.

The study presents 1970 highway service structure data, together with projections to 1990, and recommends to Congress a Federal Highway Improvement Program designed to foster smooth traffic flow in the future. Tables 2-3 and 2-4 summarize portions of this date.

Table 2-3. Highway System Linear Mileage
(Millions of Miles)

Type	1970	1990
URBAN		
Arterials	0.10	0.17
Collectors	0.04	0.08
Locals	0.35	0.57
Subtotal	0.49	0.82
RURAL		
Arterials	0.28	0.29
Collectors	0.69	0.71
Locals	2.11	2.10
Subtotal	3.08	3.10
TOTAL	3.57	3.92

Table 2-4. Highway System Traffic
(Billions of Vehicle Miles)

Type	1970	1990
URBAN		
Arterials	429	896
Collectors	46	90
Locals	102	134
Subtotal	577	1,120
RURAL		
Arterials	356	525
Collectors	121	158
Locals	66	67
Subtotal	543	750
TOTAL	1,120	1,870

It can be seen from Table 2-3 that while hardly any increase in rural mileage is projected, an approximate 66% addition to urban mileage is planned. This is consistent with the doubling of urban traffic projected for 1990 in Table 2-4.

Since this FHWA study was made, there have been several developments which suggest that its forecasts may overstate future highway construction. Over the past several years, public resistance to freeway construction in urbanized areas has increased. There are now fairly rigorous requirements for environmental impact assessment prior to highway construction. The Clean Air Act also reflects a public concern about smog and a reluctance to proceed unquestioningly with urban highway expansion. Most recently, the energy crisis has had manifold impacts. Shortages and higher prices have led to reductions in highway trust fund accumulations, and to a growing emphasis upon public transit. Also, greater use of gas tax funds for transit is in the offing (but additional funds will be required to meet the growing deficit in transit operations). As discussed in a subsequent section, no significant diversion of automobile travel to transit usage is foreseen.

At this point, the effects of these various supply considerations cannot be set forth with any precision. A subjective evaluation is made that some reduction in FHWA projections of supply (i.e., highway construction) will not significantly affect usage.

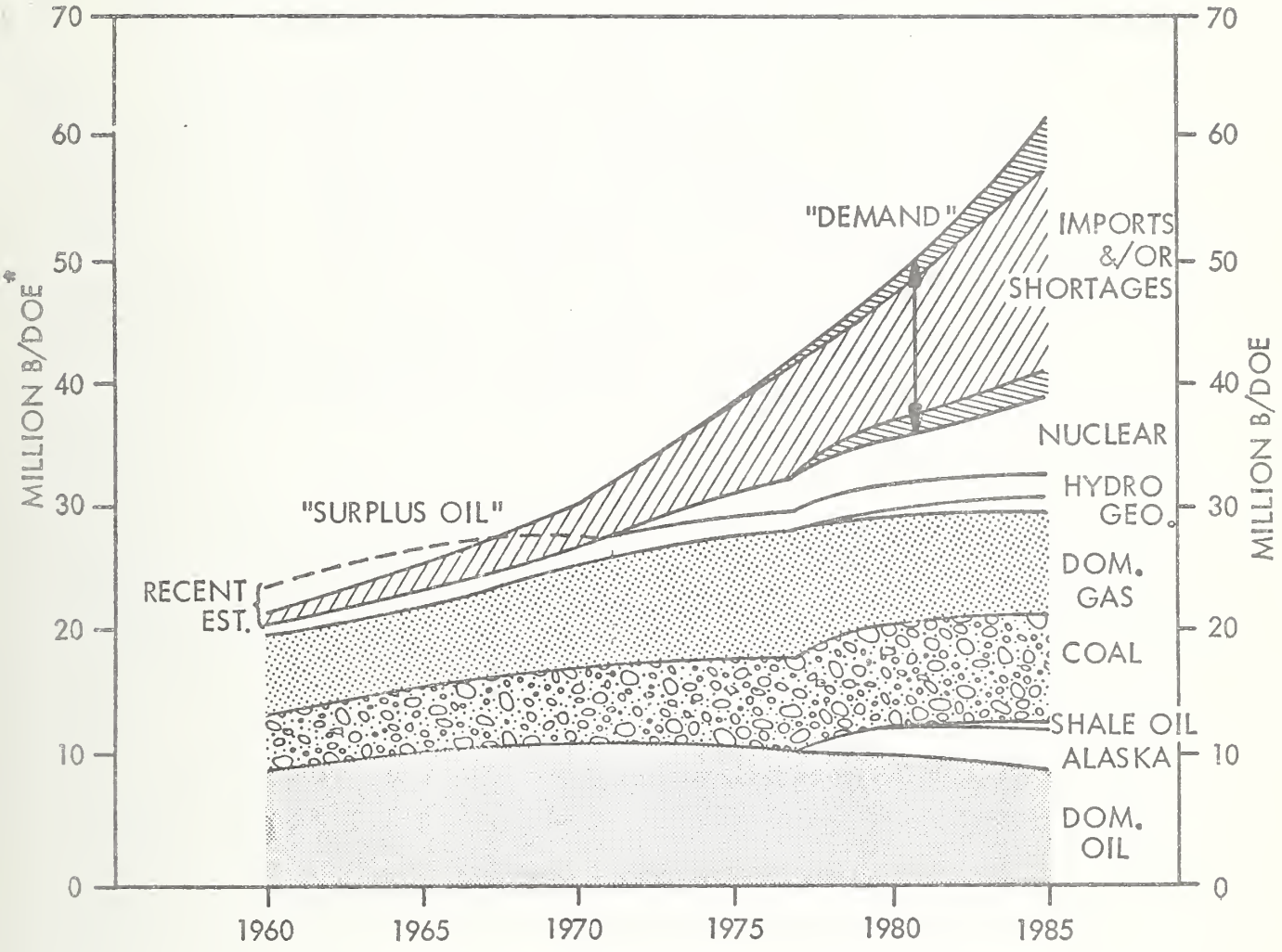
Fuel Resources. The growing gap between the domestic demand for energy and the domestic supply of energy has been evident since the 1960's. Favorable pricing of imported energy, primarily crude oil from the mid-East countries, obscured this gap until recently since all domestic energy demands were met at relatively stable and acceptable costs. In 1973, the seriousness of this gap was demonstrated when a political crisis in the mid-East resulted, not only in a temporary cutback of oil from

these soruces, but price increases of over 100% in the price of their crude oil. The 12 nation Organization of Petroleum Exporting Countries (OPEC), now wield a virtual monopoly as key suppliers of petroleum to the United States as well as other industrial nations in Europe and Asia. The future implications of U.S. dependency on imports is depicted in Figure 2-4 which projects the total U.S. demand for energy and the total domestic energy supplies from all sources.

In 1970, 95% of the energy required for transportation came from oil (petroleum) and about 53% of the oil supply in the U.S. was used for transportation, 22% of which was imported. In 1985, imported oil is projected to constitute approximately 57% of the total U.S. supply. For passenger cars, which consumed 55% of all transportation energy in 1970, the 1985 projections of oil sources have significant implications in terms of the cost per gallon, if not outright shortages.

Alternative energy sources have been suggested as solutions to decrease the dependence of the automobile on petroleum products. Unfortunately, energy consuming sectors, other than transportation, are faced with the same basic shortages and will therefore compete for these alternatives, primarily gases and electricity (which is derived from basic energy sources). Projected patterns of energy demands by competing consumer sectors indicate that the relative demand ratios by consuming sectors will be essentially the same as past and current patterns, but the energy demand rate will continue to increase. It is anticipated that the historical economic forces, in the face of increased demand and declining supply, will result in increasing costs of energy, regardless of source, into the mid-80's. Beyond the 1980 decade, increased use of nuclear energy and the development of new energy sources (solar, geothermal, organic) should stabilize, if not reverse, the near-term trends of supply and demand.

The uncertainties associated with future considerations related to energy resources (OPEC's policies on production and pricing, the global demand for their supplies, and the progress of the U.S. programs for



* B/DOE = BARRELS/DAY OF OIL EQUIVALENT

Figure 2-4 U. S. Total Energy Supply/Demand (Late '72 Data)

energy self-sufficiency) precludes any quantitative projections of the availability and costs of automotive fuels in the mid-80's. However, qualitative assessments can be made of the probable major impact of total energy projections on the automotive sector; these include the following:

1. Costs of automotive fuel will be significantly higher than current levels. The increase may result from the imposition of higher taxes designed to constrain fuel usage and to fund energy-related programs as well as the increased costs of imported fuel and fuel from new domestic sources.

2. Costs of all fuels will have a collateral effect on the raw material, fabrication, assembly, and finishing costs of automobiles, or on the availability of raw materials and parts.

In terms of usage, the effect of higher auto and fuel prices will most influence the economically marginal segments of the car buying and using population. For the majority of the driving population, the car will remain a necessity for business and personal use although with probable decreases in its non-essential uses and a preference for smaller, more economical (first and running costs) models. The usage forecasts anticipate relatively modest effects of higher fuel prices especially when the alternatives to the car are assessed as a transportation means.

Alternative Modes of Transportation. Another consideration bearing upon future automobile usage and accidents, is the future use of alternative modes of transportation. The most notable prospects are the various forms of urban transit. For over half a century, the U.S. population has migrated from rural portions of the country to the cities and then from the central cities to the suburbs. As a result in 1970, 74% of the nation's population resides in its cities and their surrounding suburbs. This general trend has been forecast to continue, so that by 1990, 82% of the population will

be living in urban areas. There have been some recent indications of a slowing and even short-term reversal of this trend. Recent economic conditions, including increases in farm prices, are thought to underlie these observations. However, it is anticipated that the basic urbanization trend will continue.

Increasing urbanization and income have resulted in more travel and greater pressure on existing urban transportation systems. During the sixties, significant changes occurred in the pattern of urban travel, with large increases in automobile travel and corresponding decreases in public transportation level. Between 1960 and 1970, urban automobile travel increased about 74%, to 737 billion passenger miles annually. Taxi travel increased about 31% during the same time period, urban bus transit decreased about 8%, and commuter rail travel remained relatively stable.

In effect, urban passenger travel by automobile has increased from 88% of all urban travel in 1960 to nearly 94% in 1970. Clearly, automobiles absorbed most of the growth in urban travel during the sixties, diverting many passengers from mass transportation.

- Characteristics of Urban Travel

The thrust of mass transit development is concentrated in urban areas. Urban travel has several characteristics which must be considered in assessing likely urban transportation alternatives for the 1985 time period.

Trip Purpose

About 50% of all public transit trips are work-oriented, in contrast to 25% of auto trips. The second most important purpose for which transit trips are made is school travel; collectively work and school transit trips constitute 65 to 70% of all transit trips. Because of the low use of public

transit for non-work purposes, transit trips constitute a small fraction of total trips. Work is the predominant purpose for taxi trips; personal business is second in importance. Together these two purposes account for about 50% of all taxi trips.

Overall, the distribution of travel by purpose has changed over time. Work travel has been declining, while social, recreational, and shopping travel has been increasing. These trends will probably continue into the future; i.e., non-work travel will increase at a faster rate than travel for work purposes.

Peaking

Urban travel exhibits a marked peaking characteristic which results from the American work-home pattern. Public transit trips in particular are becoming increasingly peaked. For example, peak-hour commuter railroad trips typically account for 20 to 25% of total daily travel; for rail transit, 15 to 20% occurs during peak hours; and for buses, peak hours handle 10 to 15% of daily travel. The peaking phenomnenon creates major problems in terms of equipment and operators required to transport peak hour passengers. As a result, the transit system sized for peak loads is under-used, a condition that causes a revenue-cost squeeze which impacts transit system profitability and viability. These two considerations constitute continuing restraints upon expanded use of public transit. Increases in the more widely scattered and flexibly scheduled social, recreational, and shopping trips places transit travel at a continuing disadvantage, and peaking results in continuing profitability problems.

Characteristics of Urban Travelers

The mode, type and amount of urban travel is directly related to the characteristics of urban travelers, and urban travel can be expected to change as these characteristics change. Personal income greatly influences the mode and number of trips by travelers. When income becomes greater,

the number of shopping, social-recreational, and personal business automobile trips made a typical household increases and the number of transit trips decrease. Because continued increases in personal income are projected, conventional transit will continue to have patronage problems.

- Projected Urban Transportation

Increasing population and income are producing and will continue to produce, if current trends continue, large increases in urban travel. Non-work related travel is increasing faster than travel for work purposes. Because urban area expansion increases trip distances, improvements in the capacity of urban transportation systems will have to made to accommodate urban travel growth.

Urban travel is determined by the characteristics of the traveler and the quality and availability of alternative transportation modes.

In order to achieve a significant and long-term diversion of traffic from passenger cars, an alternative mass transportation system must: (1) service the urban/suburban areas where no public transportation now exists, and (2) where public transportation exists, service must be enhanced to the point where it approximates the characteristics of the private automobile in terms of comfort, privacy, availability, and cost. Failure to satisfy these criteria in the past has resulted in the decline in public transportation in favor of the auto.

A number of major metropolitan areas have new or planned mass transportation systems which recognize the service requirements and have the potential of influencing usage patterns in the mid-80's. The following is a summary description of these systems.

Bay Area Rapid Transit (BART). A 75 mile train system, started in 1953, was intended to be self-supporting once capital costs were met. Inflation and rising operating costs have resulted in deficits which require state and federal subsidies. Increased fares to cover deficits

were considered to be impractical and undesirable. Since the system is not fully operational in its intended automatic control mode, there is no evidence of its success in reducing automobile traffic; it has diverted passengers from use of buses on some routes.

Denver Metro Transit (DMT). Six privately owned bus systems were taken over by the DMT and consolidated into an expanded single area-wide system. This system, financed by a bond issue and federal funding, resulted in an annual growth rate in ridership of 15% (since 1971) as opposed to a national rate of 2%. The system operates at a deficit made up by increased sales taxes. The success of the bus system led to the approval of a $425 million bond issue in 1973 to partially finance a Personal Rapid Transit (PRT) system. Construction of a PRT system with a 6,000 passenger/hour capacity, to start in 1976, is contingent on successful demonstration of PRT technology and the receipt of $850 million of federal grants to supplement the local bond funds.

Southern California Rapid Transit District (RTD). The RTD encompasses Los Angeles (city and county) and parts of Orange County. A planned rail-busway network system was defeated by voters in the November 1974 general election. Prior to the November 1974 general election, Arthur D. Little Inc. (ADL) was commissioned by the RTD to study the impact of the planned rail-busway system (including a rail network) on congestion, travel costs and time, and other community considerations. The report found that automobiles will continue to be the primary source of mobility in metropolitan Los Angeles in 1990. The biggest benefit to the average motorist switching to the system to get to work would be a saving of $1,100 per year and lessened commuting time. No estimates were made of any anticipated reductions in vehicles on the road, congestions, or other usage related factors.

Washington Metropolitan Area Transit Authority. This agency is responsible for developing the Metro system, a 98 mile rail system to provide mass transportation for the District of Columbia and limited regions of Virginia and Maryland. The first leg of the Metro was scheduled to be operational in 1972; however, construction delays were encountered and the first of six operational phases is now scheduled for June 1975 and the last phase in December 1979. It is anticipated that as a result of these delays, the loss in fare revenues to service the bond issue and the related stretchout in construction and financing costs will require additional capital outlays. Metro planners anticipated a diversion from automobile travel for work purposes and estimates were made of the resulting cost savings (benefits) for motorists using the Metro, motorists not using the Metro, bus riders, and the business community. (Data on the corresponding reductions in vehicles on the road were not published.) Significantly, the greatest estimated benefits accrue to former bus riders ($32.9 million in 1990), with motorists using the Metro receiving the second largest benefit ($58.3 million).

The Unified Transportation Assistance Program (UTAP) and the Urban Mass Transportation Administration (UMTA) are designated as the prime sources of federal funds for both highway and transportation projects, approximately $2.2 billion per year proposed at the beginning of 1974. The available funds will be subjected to a number of competitive needs: operating subsidies for existing systems; escalating costs of construction underway; highways; and for planning, procurement and construction of new transit systems. Therefore, in terms of new systems, additional capacity will be available in the forms of buses well within the mid-1980 period. The construction lead time and anticipated delays in starting new rail networks make it unlikely that these systems will have any diverting influence on projected usage. In the interim, the purchasing of new automobiles will continue to fulfill basic transportation needs.

2.2.5 An Integrated Forecast of Future Automobile Usage

In the preceding sections, the underlying factors that will determine the probable mid-80's traffic environment were discussed. This section combines these factors with vehicle data to yield forecasts of vehicle utilization by vehicle mix. Average annual mileage figures are projected, and forecasts made of vehicle populations by type, characteristic, and occupancy for various trip purposes.

Vehicle Mileage. The average annual miles driven per passenger car have increased slowly by steadily. This trend has been expected to continue because of increased demand by: (1) the increased affluence associated with an older population and subsequent increases in leisure and recreational activities, and (2) the continued, though slower, migration to the suburbs. However, more recent events will have a damping effect on this demand. Constraints imposed by higher fuel costs and possible incentives to those sharing vehicles and using public transportation will somewhat offset the impetus caused by other elements of demand. It is reasonable to expect that per-vehicle travel averages will remain in the vicinity of 10,000 miles annually through 1985.

Driver Mileage. The National Personal Transportation Study contains information as to the estimated annual average miles driven per licensed driver classified by age and sex groups. It might be expected that these averages, especially among female drivers, would increase sharply because the low birth rate would allow many more wives to join the work force. However, this work trip demand is expected to be offset by decreases in child-oriented (school, medical, social, etc.) trips. Because of off-setting constraints and demands, it is felt that these averages will remain relatively stable and can be projected to 1985 with reasonable accuracy.

These averages, applied to the estimated driver distribution in 1985, were used to project the 1985 driver milage and exposure by age and

sex groupings shown in Table 2-5. The predicted personal automobile travel demand mileages reached through this method are consistent with the projections contained in the 1972 National Transportation Report. The DOT reported projections, based upon annual growth rates for personal auto travel of 3.8% per annum from 1970 to 1980, and 2.9% per annum from 1980 to 1985, indicate a demand for 1260.8 billion passenger-auto-miles in 1985.

Table 2-5
Projected 1985 Passenger Vehicle Miles by Age and Sex Groupings
(Millions)

Age	Male Drivers	Female Drivers	Total
16-19	29,184	15,309	44,493
20-24	111,257	44,385	155,642
25-29	141,455	50,089	191,544
30-34	135,668	48,409	184,077
35-39	107,252	47,432	154,684
40-44	84,196	35,367	119,563
45-54	127,053	56,179	183,232
55-64	96,360	48,092	144,452
65 and over	45,676	33,146	78,822
TOTAL	878,101	378,408	1,256,509

Projected Number of Personal Vehicles. Section 2.2, Household Characteristics, projected the number of households by size and age of household head. This information was integrated with car ownership and other economic data to project the cars-per-household ratio. Application of this ratio (1.4+) to the projected number of households (88 million) indicates a demand for approximately 125 million personal vehicles in 1985 (a figure which also results from using projected total driver mileage and dividing by projected average vehicle mileage).

Other Vehicles. In this study, the emphasis has been largely on automobiles, however, attention must also be given to other vehicles which are part of this overall traffic environment. Some of these are possible substitutes for automobiles in fulfilling personal transportation needs.

- Trucks and Buses

A comprehensive 1985 forecast of the number of trucks and buses (by type and weight) that will share the nation's highways would require a significant effort beyond the resources available for this study. The approach taken was to base projections on an analysis of past trends and a review of industry and government forecasts. From the data underlying Figure 2-5, the proportion of trucks has remained relatively constant with a 1973 car-to-truck ratio of (81.3% ÷ 18.7% =) 4.35. Application of this ratio to the 1985 passenger car population forecast of 123.1 million results in an estimated 28.3 million trucks and buses, which compares favorably with the FHWA's Statistics Division's 1985 projection of 28.1 million trucks and buses.

It is expected that the number of buses used for public transit purposes will increase considerably over prior growth rates, especially in urban areas. However, their exposure in the overall traffic environment will be lessened by the increased use of special lanes and routes to provide more effective mass transit.

Approximately 95% of trucks are of the single-unit type. From recent trends (1970 through 1973) in new truck registrations, some 61% of these are in the light truck classification (under 6,000 pounds, mainly pickups and vans). Industry sources state the approximately 65% of the light trucks sold are used for personal and recreational activities, 20% exclusively for business, and 15% for both business and pleasure. Therefore, it can be estimated that about 40% of the nation's truck fleet is satisfying personal transportation demands. However, because of the tendency to equip

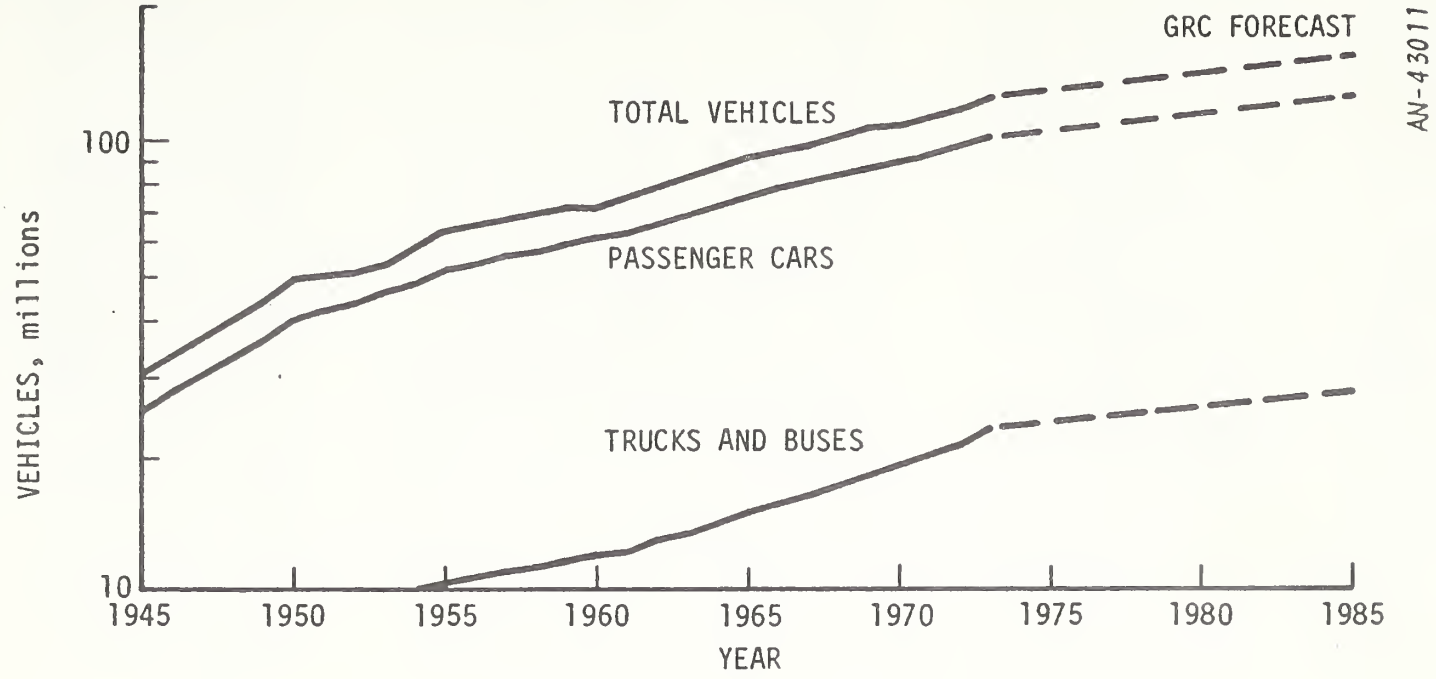


Figure 2-5 Number of Vehicle on the Nations Highways (Motorcycles excepted)

the larger percentages of these vehicles primarily for recreational purposes, it is estimated that only approximately 2.5 million should be considered as substitutes for automobiles in fulfilling the mid-80's day-to-day travel demand.

- Publicly-Owned Automobiles

Approximately 500,000 of the passenger cars presently using the nation's highways are owned by public agencies, mostly federal, state, and local governments. This figure was extended to 1985 and added to the number of automobiles forecast for personal transportation use in order to determine the portion of the total vehicle mix attributable to automobiles.

- Motorcycles

Motorcycle registrations have been increasing steadily from 1.38 million in 1965 to 4.22 million in 1973. However, recent changes in registration requirements preclude identifying those vehicles used solely for off-road recreational purposes.

An industry source indicates that approximately 75% of the motorcycles sold are purchased by 18 to 24 year old males. If this trend persists, the market will soon become saturated, especially in view of the decline of 18 to 24 year olds in the mid-80's shown in Figure 2-6. Accordingly, a continuance of present growth is forecast until saturation is reached at 8.5 million motorcycles in 1982 and that level is maintained thereafter.

Projected Market Shares of Personal Automobiles by Weight. Figure 2-7 presents the historical and projected market shares for large and small cars using general industry classifications. Unfortunately, the weight characteristics used in these classifications do not permit a unique assignment of automobiles into categories of under or over 3000 pounds,

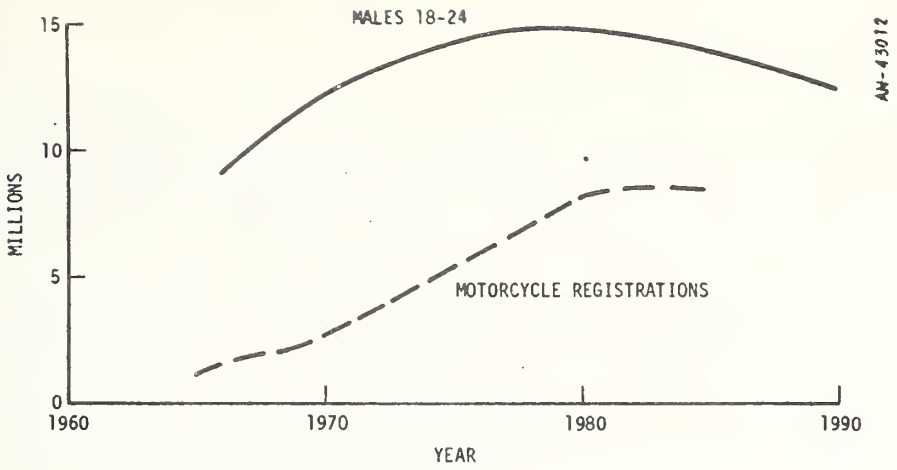


Figure 2-6. U.S. Males 18-24 Years of Age and Motorcycle Registrations

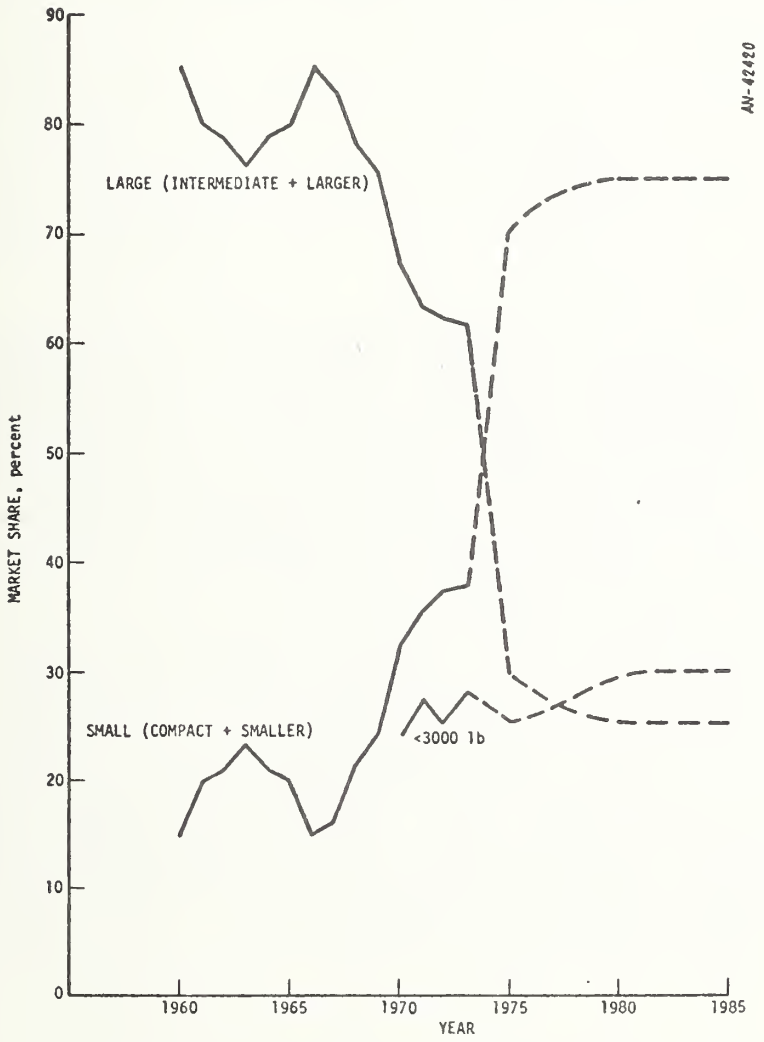


Figure 2-7. Historical and Projected Auto Sales, 1960-1985

e.g., a 6-cylinder Ford Maverick weighs 2852 pounds, an 8-cylinder Maverick weighs 3025 pounds, and a presumably compact Oldsmobile Omega weighs 3525 pounds, etc.

Figure 2-7 also shows the market share of cars under 3000 pounds from 1970 to 1973. The percentage of these vehicles dropped considerably in 1972 even though the market share of small cars increased. This was due to weight increases in various models which caused changes in category. It is expected that the addition of safety equipment and environmental controls on future models will cause further increases in weight and that more domestic models currently in the 2800 to 3000 pound categories will move into the over-3000 pound category.

At the present time, imports constitute about 15% of the U.S. car market. Domestic car makers have stated that they can "live with" a ratio in that vicinity so this percentage has been used in the 1985 projections. Approximately 97% of the imports are in the under-3000 pound category; accordingly, this percentage was also used in the projections.

Industry media have been examined to determine recent trends and the future outlook for individual automobile weights and operating life. First-quarter 1974 data indicate that small cars (compact and smaller) accounted for approximately 50% of the market. Industry sources have projected that this share will increase to between 55 and 65 percent of the market within the next few years, and other production experts predict that 55% of all domestic 1975 models will be compacts or smaller.

Considering past and present trends and industry outlooks, it is envisioned that the market share of small cars will rise sharply to 70% in 1975 (55% domestic, 15% import) with a more modest rate of increase to a saturation level of 75% in 1980. Cars in the under-3000 pound category, however, are predicted to retain a market share of approximately 30% because of the weight increases described previously.

Projected Age Profile of Automobiles. New car sales can be translated to total car population by properly accounting for the expected life of each year's automobile. These age profiles are also useful in assessing the time required for new cars with safety features to be in wide use. Analysis of historical data regarding cars in use by year of manufacture reveals that attempts to isolate the share of cars by each model year is uncertain because of yearly variations in production. However, by aggregating these cars into blocks of three years, the yearly variations are "smoothed", and trends can be discerned. After examining the age structure of cars in use from 1955 to the present (it was felt that lack of production during WW II years would distort earlier data), an extrapolation of past and present trends indicates the following car-age profile:

Age of Car	Percentage
Under 3 years	30.2
3-5 years	31.0
6-8 years	23.0
Over 8 years	15.8

Automobile Occupancy and Trip Purpose. One additional consideration for passenger cars operating in the mid-80's environment is the use they will be subjected to. Historical trends, presented in Tables 2-6 and 2-7, indicate passenger car usage in terms of trip purpose, trip length, occupancy, and their respective distributions. Corresponding data segregated according to vehicle weight or size classification is unavailable.

The original FHWA source of the tabulated data presents additional statistical details on occupancy; however, it does not discuss user motivations for car usage or the reasons for the shifts in usage occurring between the two surveys. Certain inferences can be drawn from the data exhibiting the larger changes: (1) the greater use of the car for non-business or work-related trips reflects the increased affluence of the car-owning population, (2) the increase in length of the work-related trips

Table 2-6

CAR USAGE TRENDS

MAJOR PURPOSE OF TRAVEL

PURPOSE	1951-58[1]				1969-70[2]				Δ			
	Trips	Travel	Trip* (1-way)	Occu-pants*	Trips	Travel	Trip* (1-way)	Occu-pants*	Trips	Travel	Trip	Occu-pants*
1. Earning Living												
To and from work	33.6%	26.8%	6.4	1.3	32.3%	34.1%	9.4	1.4	-1.3%	+7.3%	+3.0	+0.1
Business related	12.2	16.8	10.2	1.3	4.4	8.0	16.0	1.6	-7.8	-8.8	+5.8	+0.3
Total	45.8%	43.6%	7.4	1.3	36.7%	42.1%	10.2	1.4	-9.1%	-1.5%		
2. Family Business												
Medical and dental	1.6%	1.9%	9.7	2.0	1.8%	1.6%	8.3	2.1	+0.2%	-0.3%	-1.4	+0.1
Shopping	15.8	7.2	3.8	1.9	15.4	7.6	4.4	2.0	-0.4	+0.4	+0.6	+0.1
Other	12.1	9.9	6.8	1.8	14.2	10.4	6.5	1.9	+2.1	+0.5	+0.3	+0.1
Total	29.5%	19.0%	5.4	1.9	31.4%	19.6%	5.5	2.0	+1.9%	+0.6%		
3. Educational, Civic or Religious	7.6%	3.7%	4.1	2.4	9.4%	5.0%	4.7	2.5	+1.8%	+1.3%	+0.6	+0.1
4. Social & Recreational												
Vacations	0.1%	4.9%	296.0	2.7	0.1%	2.5%	165.1	3.3	0	-2.4%	-130.9	+0.6
Visits					9.0	12.2	12.0	2.3				
Pleasure rides	7.2	12.7	14.2	2.5	1.4	3.1	19.6	2.7				
Other	9.8	16.1	12.3	2.4	12.0	15.5	11.4	2.6				
Total	17.1%	33.7%	14.8	2.4	22.5%	33.3%	13.1	2.5	+5.4%	+0.4%		
5. All Purposes	100.0%	100.0%			100.0%	100.0%	8.9	1.9				

SOURCE DATA: (1) Automobile Facts and Figures 1968; (2) Automobile Facts and Figures 1972.

*Average Miles or Occupants

Table 2-7

CAR USAGE TRENDS

DISTRIBUTION OF TRIPS AND VEHICLE-MILES OF TRAVEL

Trip Length (One-way Miles)	1951-56[1]		1969-70[2]		Δ	
	Trips	Miles	Trips	Miles	Trips	Miles
Under 5	59.6%	13.2%	54.1%	11.1%	-5.5%	-2.1%
5 - 9	19.9	15.4	19.6	13.8	-0.3	-1.6
10 - 15	8.1	11.2	13.8	18.7	+5.7	+7.5
16 - 20	4.2	8.2	4.3	9.1	+0.1	+0.9
21 - 30	3.7	10.4	4.0	11.8	+0.3	+1.4
31 - 40	1.6	6.5	1.6	6.6	0	+0.1
41 - 50	0.8	4.3	0.8	4.3	0	0
51 - 99	1.3	10.8	1.0	7.6	-0.3	-3.2
100 and over	0.8	20.0	0.8	17.0	0	-3.0
	100%	100%	100%	100%		

SOURCE DATA:

(1) Automobile Facts and Figures 1968

(2) Automobile Facts and Figures 1972

reflects the increased movement to suburban residence, and (3) the decrease in vacation trip length reflects a diversion to air travel for long distances.

The findings of the survey of 1969-70 car usage were summarized as follows:

- Average occupancy for all trip purposes combined was 1.9 per trip.
- Average occupancy varied from a high of 3.3 per trip for vacations to a low of 1.4 per trip for "to and from work" trips with the average occupancy generally increasing with increasing trip length.
- One-occupant trips represent 50.2% of all trips.
- Approximately 74% of "to and from work" trips were in one-occupant cars.

In the projection of recent trends, two key factors bear on future automobile occupancy: (1) the projected decreases in household size, and (2) the greater proportion of non-work trips. These suggest that for non-work trips, there will be small decreases in occupancy accompanied by somewhat longer trip lengths.

Also to be considered is the effect of increasing fuel costs on occupancy and travel for all purposes. With approximately 88% of all trips not exceeding 15 miles one-way, it is unlikely that even doubling or tripling gasoline prices would significantly impact the trips made within this range. Fuel costs represent a relatively small percentage of car expenses in comparison to insurance and depreciation. Undoubtedly, increased fuel prices will curtail work-related travel for the lower income car-owning groups and those who have access to an acceptable form of public transportation and some curtailment of the discretionary social and recreational trips. Some higher occupancy can be anticipated in work trips through car-pooling. On balance, however, there is no basis to project any significant net change from these varied influences upon 1985 usage.

Summary of Projected 1985 Automobile Usage. A summary of the projected traffic environment that the RSV will operate in in the mid-80's follows. The descriptions of the environment are provided in quantitative terms where possible; qualitative descriptions or assessments are presented for those areas that don't lend themselves to numerical descriptions or projections.

- Vehicle Population and Mix

The projected total vehicle population in the U.S. is 160,400,000, and is composed of the following vehicle types:

Automobiles:	123,100,000	privately-owned
	500,000	publicly-owned
	123,600,000	total
Trucks and buses:	28,300,000	
Motorcycles:	8,500,000	

- Automobile Characteristics

The age distribution of all automobiles is estimated to be as follows:

Vehicle Age (Years)	Percent	Number of Automobiles
Under 3	33	40,790,000
3-5	34	42,020,000
6-8	21	25,960,000
Over 8	12	14,830,000
	100	123,600,000

The age distribution of the total automobile population by two basic size classifications, intermediate and larger, and compact and smaller, is estimated to be the following:

Intermediate and Larger			Compact and Smaller		
Vehicle Age (Years)	Percent	Number of Automobiles	Vehicle Age (Years)	Percent	Number of Automobiles
Under 3	25	10,200,000	Under 3	75	30,590,000
3-5	25	10,510,000	3-5	75	31,510,000
6-8	27.5	7,140,000	6-8	72.5	18,820,000
Over 8	47	6,970,000	Over 8	53	7,860,000
		34,820,000			88,780,000

Within the compact and smaller classes are those automobiles whose weight does not exceed 3000 pounds. The estimated number of vehicles in this sub-class and their age distribution as a percentage of the age groupings for all automobiles is as follows:

Vehicle Age (Years)	Percent	Number of Automobiles
Under 3	30	12,240,000
3-5	30	12,610,000
6-8	28	7,270,000
Over 8	27	4,000,000
		36,120,000

- Driving Population

The total driving population (ages 16 and over) in the U.S. in 1985 is estimated at 147.1 million out of a total potential driving population of 175.7 million. The male driving population is estimated to be 90% of the total males 16 years of age and over as contrasted to 87% in 1970. For females, the percentage increase is more marked, 78% in 1985 as opposed to 61% in 1970. The breakdown of projected male and female drivers by age groups follows.

Age	Driver Population (in millions)			% of Drivers	
	Male	Female	Total	Male	Female
16-19	5.3	4.3	9.6	75	62
20-24	9.7	8.3	18.1	94.5	83
25-29	10.1	9.0	19.2	95	86
30-34	9.4	8.4	17.8	95	86
35-39	8.2	7.6	15.8	95	87
40-44	6.4	5.9	12.4	95	85
45-54	10.1	9.6	19.7	95	84
55-64	9.1	9.0	18.1	92	78
65 and over	7.5	9.0	16.5	72	58
Totals	75.9	71.2	147.1	90	78

- Driving Patterns

The average annual miles driven per automobile will remain in the vicinity of 10,000 miles. However, in order to accommodate the greater number of vehicles on the road and continuing urbanization, the FHWA plans call for an increase in urban highway linear mileage of approximately 66% by the end of the 1980 decade, anticipating nearly twice as much vehicle miles travel on the urban system as in 1970. Rural highway mileage and vehicle miles traveled on them will experience relatively small increases in comparison.

There was no indication of any shifts in day/night or wet/dry driving patterns.

- Alternative Transportation Modes

New or proposed mass transportation systems in major metropolitan areas are anticipated to have a minimal influence in diverting travel from the automobile to a public transit system. The highest diversion estimate was 5% for the proposed Los Angeles system which, in view of its rejection by voters in its district, will probably not be realized by the mid-80's.

No evidence was found of any serious considerations being given to the use of dual-mode automobile systems. The greatest departure from the conventional bus-train networks was the proposed personal rapid transit concept being considered for Denver. This approach, similar to that being demonstrated in the Morgantown project, has yet to evidence its effectiveness as a viable alternative to the automobile or even the efficient Denver bus system. Similarly, there was no indication of any seriously proposed legislation barring vehicles (except in limited shopping mall areas in certain downtown areas) or restricting vehicle size or characteristics in local or regional areas.

- Occupancy and Travel

The travel purposes, mileage per trip purpose, and related occupancy trends are projected to be essentially the same as those reported by the 1969-1970 FHWA surveys. Influencing factors that might tend to increase certain usages and trip miles (primarily for non-work related areas) were considered to be offset by increasing fuel costs. Similarly, where decreased household size trends might result in decreased occupancy, ride-sharing trends would offset that decrease.

2.3 ACCIDENT PROJECTIONS

2.3.1 Introduction

The purpose of Section 2.3 is to provide a summary quantitative description of all major accident events. With such a data base, societal costs are estimated for the projected environments; priorities are established in terms of maximum safety payoffs; and a specific set of values based on a demonstrated need can be assigned to each related specification.

Unfortunately, there is a lack of statistically valid data, representative of nationwide experience, to describe recent accident histories in the scope and detail deemed desirable for the accident projections. Therefore, in those instances where the only available data is known to be biased, to constitute an inadequate sample, or to be otherwise suspect, the study was confronted with two disagreeable choices: (1) to by-pass the accident event; or (2) to address the event, recognizing the inadequacies of the basic sources and data. The latter alternative was selected; projections were made as necessary with the appropriate qualifications so that some insight could be had into the events of interest. Further, if more adequate data becomes available in the future, any questionable event(s) could be reassessed and modified as indicated.

2.3.2 Accident Patterns

Current accident assessment and accident projections are the most vital parts of the program definition phase. Ideally, one output of this study area should provide a comprehensive statistical data base which would:

1. Permit a definitive quantitative description of each accident event of interest, such descriptions to be representative of national experience.

2. Permit a realistic evaluation of advances in the man and environment systems that would influence the vehicle system in terms of accident involvements and their consequences.

Such a data base would enable the development of a set of performance specifications related to demonstrated needs as well as the development of the projections of the accident environment required to characterize the RSV.

Accident Descriptions. Accidents involving passenger cars were categorized into the following six classes, listed in a decreasing order of importance relative to the fatalities currently associated with each class:

1. Vehicle with other vehicles
2. Non-collisions
3. Vehicle with pedestrians
4. Collisions with fixed objects
5. Vehicle with motorcycles
6. Vehicle with pedalcycles

These categories or classifications are essentially the same as those used the National Safety Council (NSC) and by state and county agencies when compiling and reporting accident statistics. Unfortunately, in many instances while compiling and reporting accidents, motorcycles were classified as "motor vehicles". As a result, the term vehicle pertains to automobiles and motorcycles. Therefore, motorcycle accident statistics are included in the above accident categories. When the car-with-motorcycle category is evaluated, the motorcycle data is segregated (insofar as possible in view of the limited data) from overall motor vehicle accidents.

Two other accident categories, used by the NSC: collision with railroad trains, and "other collisions", were not considered in this study.

The difference in mass between passenger cars and trains is such that vehicle countermeasures are inappropriate; the logical countermeasure in this accident case is in the grade crossing area. The "other" category, usually entails collisions with animals, and is comparatively infrequent. The countermeasures which may be applied to the RSV to cope with the vehicle to vehicle and other accident classes considered should provide benefits to the "other" case.

For each accident class, descriptors of the accident in terms of variables of interest were identified by means of a tree format. The common variables in each case were the geographical location (urban, rural), the time of day or lighting conditions (day, night), and the road condition (wet, dry). Below these levels of variables, unique variables for each accident class were identified. For each variable level, the desired accident data included, as a minimum, the total number of accidents (N), fatalities (F), injuries (I), and property damage (D). A summary of the unique variables associated with each accident category considered follows.

- Vehicle With Other Vehicles

Two weight ranges were considered, small cars under 3000 pounds (W_1) and large cars and vehicles over 3000 pounds (W_2). Three types of vehicle to vehicle collisions, frontal, side, and rear, were selected with each collision type involving different pairings of the small car and the large vehicle. Detailed data on collisions involving pairs of large vehicles were not required. The final variable was the relative speed at impact specified in one of four speed ranges.

- Non-Collision

The unique variables of interest are the car weight, road geometry, and speed. The non-collision event of prime interest is overturning involving the small car on straight and on curved roads and at each of two speed groupings.

- Vehicle With Pedestrian

The unique variables in the car impacts with pedestrians are the car area impacting the pedestrian, car weight, speed at impact, and the pedestrian age. Three impact areas are considered; prime interest is in frontal impacts with side and rear impacts of lesser interest. For the frontal impact, two car weight ranges are considered; prime interest is centered on the small car in accidents occurring in each of three speed at impact groupings. For each speed at impact group, three pedestrian age groups, approximating three different body sizes, comprised the final variable.

- Vehicle With Fixed Objects

The unique variables for this class are: the struck object, its geometry, the car weight, the impacting area of the car, and the speed at impact. The object of interest is rigid; the geometries of interest are the cylindricals (tress, poles, hydrants, etc.) and the planes (abutments, walls, barriers, etc.). The car of prime interest is the small one involved in frontal and side impacts with the identified rigid objects at each of three impact speed groupings.

- Vehicle With Motorcycles

Three unique variables are considered in the car with motorcycle collisions. The impact area includes the car front impacting the motorcycle, the motorcycle impacting the car side, and the motorcycle striking the car rear. The car of prime interest is the small car involved in frontal and side impacts in each of three speed at impact groupings.

- Vehicle With Pedalcycles

The unique variables in this class are essentially the same as those for the car with motorcycle class except that the accident where the bicycle strikes the rear of the car was not considered.

- Causal Data

In addition to the described variables, additional descriptive data of causal factors attributed to the vehicle in each accident class was desired. The factors of interest are primarily those associated with accident avoidance and functional systems and which, because of inadequate design or performance, are primary or contributing causes of accidents. Typical systems of interest are the driver's sight line and visual aids, lighting and signaling, vehicle stability in braking while turning or in running off the road, etc. Unfortunately, such data is not reported in mass accident statistics, and where such data is available, it is the subject of special studies. Therefore, no attempt was made to formalize such causal data needs, but rather to conduct literature searches for specific systems as part of the characterization and specification development tasks.

The description of the data sources and the contents of the available statistical data from each source used to describe the current accident environment follows.

Accident Data. Ideally, a study of nationwide accidents would draw upon a single authoritative source for comprehensive, detailed, and consistently defined accident information. In fact, no such single source exists. There are several sources of nationwide data, but these do not provide the detail required for the RSV program. Therefore, sources which do provide more detailed information about motor vehicle accidents, but are necessarily less extensive in their geographic coverage, were also examined.

Accident data are available in three broad categories, or levels of detail:

1. Nationwide data with summary descriptions of overall accident characteristics.

2. Regional data with a full scope of accident types and fairly detailed descriptions of each major class of accident.

3. Regional or local data which provides still greater detail for a more narrowly-defined set of accident types.

These various limitations in scope and detail of available accident data pose a number of problems in trying to set forth a comprehensive assessment of vehicle accidents; most notably, the question of using regional data to infer nationwide accident characteristics.

- Nationwide Data Sources (Level I)

There are several sources which compile nationwide data. For many years, the National Safety Council (NSC) has been publishing national statistics in their annual report, Accident Facts. The NSC data is widely accepted and used, although it is not universally endorsed as a valid representation of the nation's vehicle safety problems. Following a review of other nationwide data sources, the NSC information was selected to represent overall national accident conditions.

The Department of Transportation's National Highway Traffic Safety Administration (NHTSA) collects data from various state and local government agencies as well as from private organizations. NHTSA's National Accident Summary (NAS) and Fatality Analysis File (FAF) are based upon extensive data from many, but not all, states, thus their total numbers cannot be used directly to indicate overall national statistics. But proportionate distributions of accident characteristics from these two files can be used, and were so employed in this study.

Nationwide accident data are also compiled and published by several insurance organizations, notably the Travelers Insurance Company and the Insurance Information Institute. The Travelers Insurance Company

publishes data, which are reproduced in part in the Statistical Abstract and other government sources. The Insurance Information Institute compiles data which are also published in the Statistical Abstract and some limited use was made of this data.

Noting that there have been a number of extensive data collection and reporting programs within individual states, the suitability of these sources as representative samples of nationwide traffic and accident conditions was examined. If characteristics of the population and traffic environment in some states are similar to national descriptors, then the reported accident statistics might reasonably be assumed to represent a national sample. This possibility was explored by using techniques of mathematical statistics (factor analysis); however, this approach was unproductive.

- State and Regional Data Sources (Level 2)

There are a number of states which publish periodic, detailed reports of traffic accidents, California, North Carolina and New York being the most extensive; the characteristics of each of these states is sufficiently distinctive to require great care in using the reported data. These data sources were used to rationalize selected details within aggregate national accident categories and in making comparisons with other information. Oregon, Washington and other state data were also used for selected detail.

There are a number of specialized institutions which compile state and regional accident data. Calspan (New York), the University of North Carolina's Highway Safety Research Center (HSRC), and the University of Michigan's Highway Safety Research Institute (HSRI), compile accident statistics and carry out extensive related research activities. Data from these sources is generally more useful than the state publications because it provides greater detail, and is typically computerized so that data

classifications can be tailored to meet the needs of the user. HSRI has been maintaining data files from a number of regions throughout the country, including two counties in Michigan and one (each) in Texas, Colorado, Washington, and Florida. This study used the HSRI accident data from Oakland County, Michigan; this choice was predicated on the availability of specific detail desired for the RSV study, and the comparative ease with which it could be obtained.

- Multidisciplinary Accident Investigation (MDAI) Data (Level 3)

This data stems from an in-depth investigation of an accident by a number of highly trained accident investigation teams. These teams are sponsored by the National Highway Traffic Safety Administration, the MVMA and Canadian Department of Transportation. The information generated by these teams is recorded on the General Motors' Collision Performance and Injury Report (Revision 3) which lists over 800 different variables (descriptive items).

These detailed investigations are one source of data in the analysis of traffic accidents and must be compared with mass police data in order to infer the frequency distribution of certain classes of accident events. In effect, a synthesis of the levels permits a search for relationships or patterns which is impossible or unrealistically biased if the levels are used apart from each other.

It is recognized that MDAI files do not contain a cross section of typical accidents. The files are biased toward the more severe accidents since one of the criteria for case selection is that at least one vehicle must be towed from the accident scene. The in-depth data were prepared to cover the circumstances, causes, and effects of the collisions studied from the point of view of several disciplines. The one drawback of this file for national data statistics is its size and the emphasis put on investigation of fatal or severe accidents. Thus, the extrapolation of fatalities from this source would significantly overstate the national numbers. The file

does contain a wide variety of accident types from many geographical regions which are reported accurately by professionals at a level of detail not available elsewhere. Specifically, the reported ratio of the number of accidents that resulted only in property damage to the number of accidents resulting in death or injury in the MDAI files is 0.25:1 in contrast to the nationwide ratio of 11:1.

In this study, the CPIR data file was used in a limited way. The file was used to determine the impact speeds of struck and striking cars for front, side and rear end collisions in both the urban and rural traffic environment. The intent was to provide a measure of severity (fatalities, injuries, and property damage) for impact speed ranges. The CPIR file was the only source available which reliably reports impact speeds.

2.3.3 Accident Assessment and Projections

The discussion in Section 2.3.2 noted that accident data are available in three broadly-defined categories, each of which is limited in scope or in the level of desired detail. The central consideration in the use of these data is to draw upon them in such a way that they are reasonably representative of the national condition which is being portrayed.

The overall framework, or structure, within which the various data sources are used is as follows:

- Nationwide data is used to establish the number and distribution of accidents within broad categories of accident types, traffic environment and driver characteristics. To the extent practicable, these data are also used to establish the recent time trends of accident patterns.
- The more detailed data from regional sources are used to establish greater definition within the individual accident categories. The regional sources provide percentage distributions for further disaggregation of the nationwide data.

For example, from nationwide data, the number of fatal accidents involving two-vehicle collisions in rural areas can be identified. Regional data are then used to identify the percentage distribution of point of impact, given that there has been a fatal two-car, rural collision. Another still more detailed "level" of regional data is employed for some additional accident detail.

In short, the analysis of accident data is carried out by integrating three levels of data. While the "population" from which the data for the three levels are taken is successively less representative of national conditions, the data are used with successively less assumptions. The result is a detailed description which is a representative best estimate of nationwide accident patterns.

The general methods used to forecast accidents warrant comment. In the course of this study, the applicability of various forecasting procedures were considered, and other studies of accident determinants and future accident conditions were reviewed. Needless to say, there are a multitude of factors involving vehicles, drivers and passengers, and the traffic environment which influence the number and character of automobile accidents. The task of identifying cause-and-effect is greatly complicated by the fact that so many of these factors are interrelated and so many are inadequately documented. Driver age, driving habits, and type of automobile are closely interrelated, but simplified statistical correlations of any one of these characteristics with accident rates leads to specious inferences of cause-and-effect. On the other hand, the close interrelationship among explanatory variables can simplify the task of forecasting. If the interrelationships continue to prevail, then an account of variations in one parameter can capture much of the influence of others.

The possibility of direct mathematical projections of historical accident statistics was explored, including a review of the studies by the National Bureau of Standards which examine various mathematical forecasting procedures. Aggregate time-series projections, including various "smoothing" techniques, presume an underlying consistency into the future of population- and transportation-related factors. In the usage projection section of this report, it was indicated that this presumption would not be valid. Moreover, there are several current and pending influence factors which bear directly upon accidents and represent direct deviations from historical precedents. The recently legislated reduction in speed limits coupled with higher gasoline prices seems to have affected accident rates. The pending implementation of new motor vehicle safety features will also have an impact upon future accidents, as will proposed programs to control drunk-driving and to remove or shield dangerous roadside objects.

The procedures used in this study are a compromise between mathematical projections and subjective estimates. From reviews of accident studies, driver age emerges as the strongest single influence on accident rates. Thus a central element of the forecasting procedure for most accident types is a separate accounting of accidents for each age group (Section 2.2 indicates the significant shifts in age structure of the driving population which will take place by 1985). Recent historical data were examined to discern any year-to-year trends in involvement rates, i.e., the ratio of drivers in accidents to total number of drivers. These time trends are taken into account in forecasting to 1985. In developing 1985 projections, adjustments are also made to reflect the anticipated increase or urban driving and of small car usage. In defining the details of day-night and wet-dry occurrences, plus distributions of point of impact, no change from existing proportions was assumed.

In the subsections that follow, forecasts of accidents are presented for the classes of vehicle accidents described in Section 2.3.2. The baseline

forecasts are made exclusive of the effects of a number of influence factors which have potential significant impacts on future accident rates. Among these factors are the various Highway Safety Program Standards established under the Highway Safety Act of 1966. The impact of these standards can only be assessed on the basis of judgment, and thus are treated separately from the baseline projections.

2.3.4 Summarized Accident Data

Accident Totals. A summary of accident data developed in Volume II is presented in Table 2-8. The table lists the accident categories in order of the number of casualty accidents projected for 1985. A casualty accident is an accident which results in either, or both, a fatality or injury (i.e., damage-only accidents are not included).

Table 2-9 shows the relative occurrence of accidents, fatalities, and injuries by accident category. Out of all traffic casualty accidents involving an automobile, vehicle-to-vehicle accidents account for more than 78% of the total. The ratio of registered automobiles weighing less than 3000 lbs to the total number of registered automobiles is approximately 0.3. Note in Table 2-9 that for accidents and injuries, all accident categories except vehicle rollover show that the involvement of automobiles under 3000 pounds is slightly less than the registration ratio. However, for vehicle rollover, the involvement ratio of automobiles under 3000 pounds is significantly higher than the registration ratio.

Out of 123.6 million automobiles projected to be operating in 1985, slightly more than 3% will be involved in a casualty accident. This reflects a 3.5% drop from the 1972 involvement rate.

Table 2-8. Accident Summaries for 1972 and 1985

	Casualty Accidents		Fatalities		Injuries	
	1972	1985	1972	1985	1972	1985
Vehicle-Vehicle	2,607,000	3,199,000	24,200	29,700	4,303,000	5,263,000
Vehicle-Fixed Object	340,400	426,800	12,200	15,300	481,000	589,100
Vehicle-Pedestrian	217,800	279,300	10,700	11,800	277,000	283,800
Vehicle-Motorcycle*	(63,200)	(96,700)	(1,800)	(2,700)	(61,400)	(94,000)
Vehicle-Pedalcycle	94,600	88,500	1,100	1,100	98,000	91,800
Rollover	66,700	81,900	4,100	5,100	94,500	115,900
TOTALS	3,326,500	4,075,500	52,300	63,000	5,253,900	6,343,600

*Included in Vehicle-Vehicle Category.

Table 2-9. 1985 Projected Accident Summary

	Casualty Accidents				Fatalities			Injuries		
	Number	% of Total	Accidents Per Auto*	% Involvement Under 3000 lbs	Number	% of Total	% Involvement Under 3000 lbs	Number	% of Total	% Involvement Under 3000 lbs
Vehicle-Vehicle	3,199,000	78.5	.0259	25.3	29,700	47.2	28.7	5,263,000	83.0	25.3
Vehicle-Fixed Object	426,800	10.5	.0035	27.9	15,300	24.3	40.8	589,100	9.3	26.1
Vehicle-Pedestrian	279,300	6.9	.0023	25.3	11,800	18.7	28.6	283,800	4.5	25.2
Vehicle-Motorcycle**	(96,700)		.0008	24.9	(2,700)		24.9	(94,000)		24.9
Vehicle-Pedalcycle	88,500	2.1	.0007	24.9	1,100	1.7	35.8	91,800	1.4	24.9
Rollover	81,900	2.0	.0007	45.0	5,100	8.1	45.0	115,900	1.8	45.0
TOTALS	4,075,500	100.0	.0338	26.0	63,000	100.0	32.7	6,343,600	100.0	25.7

*123,600,000 operating automobiles.
**Included in Vehicle-Vehicle Category.

Accident Distribution by Weight, Speed and Direction. In the following tables, the data for each accident category are summarized to indicate the distribution of casualty accidents, fatalities, and injuries. These tables describe the data in terms of the following variables: automobile weight class, impact direction, and relative impact speed. These data are summarized directly from the appendices in Volume II.

- Vehicle-Vehicle

Summarized data for this accident mode, taken from Appendix A, Volume II, are presented in Tables 2-10 and 2-11. The distribution of this data between wet/dry and day/night conditions are found in Section 3.2.3, Volume II. Data disaggregated by urban/rural location is presented in Appendix A, Volume II.

- Vehicle-Fixed Object

Tables 2-12 and 2-13 present the summarized data taken from Appendix C, Volume II. Additional distributions of this data between wet/dry and day/night conditions are found in Section 3.2.3, Volume II. In Appendix C, Volume II, this data is described in terms of the object-shape variable (e.g., cylindrical, flat breakaway, flat rigid and other) and urban/rural location.

- Vehicle-Pedestrian

The summarized data for this accident mode, taken from Appendix B, Volume II, is presented in Tables 2-14 and 2-15. Additional distributions of this data by age-group involvement and urban/rural location is also presented in Appendix B.

- Vehicle-Motorcycle

Tables 2-16 and 2-17 present the summarized data taken from Appendix F, Volume II. Additional distributions of this data between urban/rural location and day/night condition are also presented in Appendix F.

Table 2-10. Vehicle-Vehicle (under 3000 lb) 1985 Projected Accident Summary

		Relative Impact Speed (mph)								TOTAL	
		0-20		20-40		40-60		Over 60			
		Number	%	Number	%	Number	%	Number	%	Number	%
Casualty Accident Vehicles	Front	476,500	29.4	342,000	21.1	111,800	6.9	56,700	3.5	987,000	60.9
	Side	129,700	8.0	64,800	4.0	8,100	0.5	1,600	0.1	204,200	12.6
	Rear	366,300	22.6	58,400	3.6	4,900	0.3	-	-	429,600	26.5
	TOTAL	972,500	60.0	465,200	28.7	124,800	7.7	58,300	3.6	1,620,800	100.0
Fatalities	Front	300	3.5	900	10.3	1,100	12.6	3,900	45.8	6,200	72.2
	Side	700	8.0	500	6.1	400	4.9	200	1.8	1,800	20.8
	Rear	500	5.9	90	1.0	10	0.1	-	-	600	7.0
	TOTAL	1,500	17.4	1,490	17.4	1,510	17.6	4,100	47.6	8,600	100.0
Injuries	Front	393,400	29.5	282,800	21.2	92,000	6.9	42,700	3.2	810,900	60.8
	Side	108,000	8.1	53,300	4.0	6,700	0.5	-	-	168,000	12.6
	Rear	302,800	22.7	48,000	3.6	4,000	0.3	-	-	354,800	26.6
	TOTAL	804,200	60.3	384,100	28.8	102,700	7.7	42,700	3.2	1,333,700	100.0

Table 2-11. Vehicle-Vehicle (over 3000 lb) 1985 Projected Accident Summary

		Relative Impact Speed (mph)								TOTAL	
		0-20		20-40		40-60		Over 60			
		Number	%	Number	%	Number	%	Number	%	Number	%
Casualty Accident Vehicles	Front	1,394,600	29.2	998,200	20.9	329,600	6.9	167,200	3.5	2,889,600	60.5
	Side	367,800	7.7	181,500	3.8	23,900	0.5	-	-	573,200	12.0
	Rear	1,117,600	23.4	181,500	3.8	14,300	0.3	-	-	1,313,400	27.5
	TOTAL	2,880,000	60.3	1,361,200	28.5	367,800	7.7	167,200	3.5	4,776,200	100.0
Fatalities	Front	800	3.7	2,300	10.9	2,800	13.2	10,200	48.2	16,100	76.0
	Side	1,500	7.0	1,100	5.4	900	4.3	300	1.6	3,900	18.3
	Rear	1,000	4.8	200	0.8	20	0.1	-	-	1,220	5.7
	TOTAL	3,300	15.5	3,600	17.1	3,720	17.6	10,500	49.8	21,220	100.0
Injuries	Front	1,151,100	29.3	825,000	21.0	267,200	6.8	121,800	3.1	2,365,100	60.2
	Side	302,600	7.7	149,300	3.8	19,600	0.5	-	-	471,500	12.0
	Rear	931,100	23.7	149,300	3.8	1,200	0.3	-	-	1,092,200	27.8
	TOTAL	2,384,800	60.7	1,123,600	28.6	298,600	7.6	121,800	3.1	3,928,800	100.0

Table 2-12. Vehicle-Fixed Object (under 3000 lb) 1985 Projected Accident Summary

		Relative Impact Speed (mph)								TOTAL	
		0-20		20-40		40-60		Over 60			
		Number	%	Number	%	Number	%	Number	%	Number	%
Casualty Accidents	Front	32,000	26.9	46,300	38.9	16,100	13.5	2,900	2.4	97,200	81.9
	Side	7,900	6.6	5,400	4.5	2,000	1.7	400	0.3	15,600	13.1
	Rear	4,900	4.1	800	0.7	500	0.4	-	-	6,200	5.2
	TOTAL	44,800	37.6	52,500	44.1	18,600	15.6	3,300	2.7	119,000	100.0
Fatalities	Front	200	3.3	1,600	24.9	1,700	27.8	800	12.3	4,300	68.3
	Side	400	6.4	600	9.1	400	6.2	200	2.8	1,600	24.5
	Rear	100	1.8	200	2.5	200	2.9	-	-	500	7.2
	TOTAL	700	11.5	2,400	36.5	2,300	36.9	1,000	15.1	6,400	100.0
Injuries	Front	42,300	27.5	60,600	39.4	20,400	13.3	3,400	2.2	126,700	82.4
	Side	9,800	6.4	6,600	4.3	2,200	1.4	3,100	2.0	18,700	12.3
	Rear	6,500	4.2	1,100	0.7	600	0.4	-	-	8,200	5.3
	TOTAL	58,600	38.1	68,300	44.4	23,200	15.1	3,500	2.4	153,600	100.0

Table 2-13. Vehicle-Fixed Object (over 3000 lb) 1985 Projected Accident Summary

		Relative Impact Speed (mph)								TOTAL	
		0-20		20-40		40-60		Over 60			
		Number	%	Number	%	Number	%	Number	%	Number	%
Casualty Accidents	Front	87,400	28.4	127,400	41.4	44,000	14.3	8,000	2.6	266,800	86.7
	Side	14,500	4.7	8,900	2.9	3,100	1.0	600	0.2	27,100	8.8
	Rear	11,100	3.6	1,800	0.6	900	0.3	-	-	13,800	4.5
	TOTAL	113,000	36.7	138,100	44.9	48,000	15.6	8,600	2.8	307,700	100.0
Fatalities	Front	400	4.2	2,700	30.3	3,100	34.1	1,400	14.9	7,600	83.5
	Side	400	4.2	600	6.2	400	4.2	200	1.9	1,600	16.5
	Rear	-	-	-	-	-	-	-	-	-	-
	TOTAL	800	8.4	3,300	36.5	3,500	38.3	1,600	16.8	9,200	100.0
Injuries	Front	125,400	28.8	179,800	41.3	60,500	13.9	10,000	2.3	375,700	86.3
	Side	20,900	4.8	13,100	3.0	4,400	1.0	8,700	0.2	39,100	9.0
	Rear	16,100	3.7	2,600	0.6	1,700	0.4	-	-	20,400	4.7
	TOTAL	162,400	37.3	195,500	44.9	66,600	15.3	10,700	2.5	435,200	100.0

Table 2-12. Vehicle-Fixed Object (under 3000 lb) 1985 Projected Accident Summary

		Relative Impact Speed (mph)								TOTAL	
		0-20		20-40		40-60		Over 60			
		Number	%	Number	%	Number	%	Number	%	Number	%
Casualty Accidents	Front	32,000	26.9	46,300	38.9	16,100	13.5	2,900	2.4	97,200	81.9
	Side	7,900	6.6	5,400	4.5	2,000	1.7	400	0.3	15,600	13.1
	Rear	4,900	4.1	800	0.7	500	0.4	-	-	6,200	5.2
	TOTAL	44,800	37.6	52,500	44.1	18,600	15.6	3,300	2.7	119,000	100.0
Fatalities	Front	200	3.3	1,600	24.9	1,700	27.8	800	12.3	4,300	68.3
	Side	400	6.4	600	9.1	400	6.2	200	2.8	1,600	24.5
	Rear	100	1.8	200	2.5	200	2.9	-	-	500	7.2
	TOTAL	700	11.5	2,400	36.5	2,300	36.9	1,000	15.1	6,400	100.0
Injuries	Front	42,300	27.5	60,600	39.4	20,400	13.3	3,400	2.2	126,700	82.4
	Side	9,800	6.4	6,600	4.3	2,200	1.4	3,100	2.0	18,700	12.3
	Rear	6,500	4.2	1,100	0.7	600	0.4	-	-	8,200	5.3
	TOTAL	58,600	38.1	68,300	44.4	23,200	15.1	3,500	2.4	153,600	100.0

Table 2-13. Vehicle-Fixed Object (over 3000 lb) 1985 Projected Accident Summary

		Relative Impact Speed (mph)								TOTAL	
		0-20		20-40		40-60		Over 60			
		Number	%	Number	%	Number	%	Number	%	Number	%
Casualty Accidents	Front	87,400	28.4	127,400	41.4	44,000	14.3	8,000	2.6	266,800	86.7
	Side	14,500	4.7	8,900	2.9	3,100	1.0	600	0.2	27,100	8.8
	Rear	11,100	3.6	1,800	0.6	900	0.3	-	-	13,800	4.5
	TOTAL	113,000	36.7	138,100	44.9	48,000	15.6	8,600	2.8	307,700	100.0
Fatalities	Front	400	4.2	2,700	30.3	3,100	34.1	1,400	14.9	7,600	83.5
	Side	400	4.2	600	6.2	400	4.2	200	1.9	1,600	16.5
	Rear	-	-	-	-	-	-	-	-	-	-
	TOTAL	800	8.4	3,300	36.5	3,500	38.3	1,600	16.8	9,200	100.0
Injuries	Front	125,400	28.8	179,800	41.3	60,500	13.9	10,000	2.3	375,700	86.3
	Side	20,900	4.8	13,100	3.0	4,400	1.0	8,700	0.2	39,100	9.0
	Rear	16,100	3.7	2,600	0.6	1,700	0.4	-	-	20,400	4.7
	TOTAL	162,400	37.3	195,500	44.9	66,600	15.3	10,700	2.5	435,200	100.0

Table 2-14. Vehicle-Pedestrian (under 3000 lb) 1985 Projected Accident Summary

		Relative Impact Speed (mph)						TOTAL	
		0-20		20-40		Over 40			
		Number	%	Number	%	Number	%	Number	%
Casualty Accidents	Front	35,500	50.3	25,300	35.8	800	1.2	61,600	87.3
	Side	3,500	4.9	2,300	3.3	100	0.1	5,900	8.3
	Rear	3,100	4.4	-	-	-	-	3,100	4.4
	TOTAL	42,100	59.6	27,600	39.1	900	1.3	70,600	100.0
Fatalities	Front	1,300	39.8	1,700	49.4	300	10.2	3,300	99.4
	Side	20	0.6	-	-	-	-	20	0.6
	Rear	-	-	-	-	-	-	-	-
	TOTAL	1,320	40.4	1,700	49.4	300	10.2	3,320	100.0
Injuries	Front	36,200	50.7	25,100	35.1	600	0.9	61,900	86.7
	Side	3,600	5.0	2,600	3.6	100	0.1	6,300	8.7
	Rear	3,300	4.6	-	-	-	-	3,300	4.6
	TOTAL	43,100	60.3	27,700	38.7	700	1.0	71,500	100.0

Table 2-15. Vehicle-Pedestrian (over 3000 lb) 1985 Projected Accident Summary

		Relative Impact Speed (mph)						TOTAL	
		0-20		20-40		Over 40			
		Number	%	Number	%	Number	%	Number	%
Casualty Accidents	Front	103,900	49.8	73,700	35.3	2,500	1.2	180,100	86.3
	Side	9,800	4.7	6,900	3.3	200	0.1	16,900	8.1
	Rear	11,700	5.6	-	-	-	-	11,700	5.6
	TOTAL	125,400	60.1	80,600	38.6	2,700	1.3	208,700	100.0
Fatalities	Front	3,130	37.2	3,890	46.2	800	9.5	7,820	92.9
	Side	50	0.6	70	0.8	20	0.2	140	1.6
	Rear	460	5.5	-	-	-	-	460	5.5
	TOTAL	3,640	43.3	3,960	47.0	820	9.7	8,420	100.0
Injuries	Front	106,600	50.2	73,900	34.8	1,900	0.9	182,400	85.9
	Side	10,600	5.0	7,200	3.4	200	0.1	18,000	8.5
	Rear	11,900	5.6	-	-	-	-	11,900	5.6
	TOTAL	129,100	60.8	81,100	38.2	2,100	1.0	212,300	100.0

Table 2-16. Vehicle-Motorcycle (under 3000 lb) 1985 Projected Accident Summary

		Relative Impact Speed (mph)								TOTAL	
		0-20		20-40		40-60		Over 60			
		Number	%	Number	%	Number	%	Number	%	Number	%
Casualty Accidents	Front	3,800	15.8	3,500	14.4	4,700	19.5	2,000	8.5	14,000	58.2
	Side	300	1.4	3,400	14.0	3,400	14.0	1,600	6.8	8,700	36.2
	Rear	100	0.4	500	2.0	600	2.4	200	0.8	1,400	5.6
	TOTAL	4,200	17.6	7,400	30.4	8,700	35.9	3,800	16.1	24,100	100.0
Fatalities	Front	110	15.8	100	14.4	130	19.5	60	8.5	400	58.2
	Side	10	1.4	90	14.0	90	14.0	50	6.8	240	36.2
	Rear	-	0.4	10	2.0	20	2.4	10	0.8	40	5.6
	TOTAL	120	17.6	200	30.4	240	35.9	120	16.1	680	100.0
Injuries	Front	3,700	15.8	3,400	14.4	4,600	19.5	2,000	8.5	13,700	58.2
	Side	300	1.4	3,300	14.0	3,300	14.0	1,600	6.8	8,500	36.2
	Rear	100	0.4	500	2.0	600	2.4	200	0.8	1,400	5.6
	TOTAL	4,100	17.6	7,200	30.4	8,500	35.9	3,800	16.1	23,600	100.0

Table 2-17. Vehicle-Motorcycle (over 3000 lb) 1985 Projected Accident Summary

		Relative Impact Speed (mph)								TOTAL	
		0-20		20-40		40-60		Over 60			
		Number	%	Number	%	Number	%	Number	%	Number	%
Casualty Accidents	Front	11,500	15.8	10,500	14.4	14,200	19.5	6,200	8.5	42,400	58.2
	Side	1,000	1.4	10,200	14.0	10,200	14.0	4,900	6.8	26,300	36.2
	Rear	300	0.4	1,500	2.0	1,800	2.4	600	0.8	4,200	5.6
	TOTAL	12,800	17.6	22,200	30.4	26,200	35.9	11,700	16.1	72,900	100.0
Fatalities	Front	320	15.8	290	14.4	390	19.5	170	8.5	1,170	58.2
	Side	30	1.4	280	14.0	280	14.0	140	6.8	730	36.2
	Rear	10	0.4	40	2.0	50	2.4	20	0.8	120	5.6
	TOTAL	360	17.6	610	30.4	720	35.9	330	16.1	2,020	100.0
Injuries	Front	11,200	15.8	10,200	14.4	13,800	19.5	6,000	8.5	41,200	58.2
	Side	1,000	1.4	9,900	14.0	9,900	14.0	4,800	6.8	25,600	36.2
	Rear	300	0.4	1,400	2.0	1,700	2.4	600	0.8	4,000	5.6
	TOTAL	12,500	17.6	21,500	30.4	25,400	35.9	11,400	16.1	70,800	100.0

- Vehicle-Pedalcycle

The summarized data for this accident category are presented in Tables 2-18 and 2-19. Additional distributions of this data are given in Volume II: age-group involvement, Section 3.2.3; and urban/rural location, Appendix D.

- Rollover

Table 2-20 presents the summarized data taken from Appendix E, Volume II. Additional distribution of this data between urban/rural location is also presented in Appendix E.

Table 2-18. Vehicle-Pedalcycle (under 3000 lb) 1985 Projected Accident Summary

		Relative Impact Speed (mph)						TOTAL	
		0-20		20-40		Over 40			
		Number	%	Number	%	Number	%	Number	%
Casualty Accidents	Front	10,100	46.0	7,100	32.1	200	0.9	17,400	79.0
	Side	1,300	5.8	900	4.1	20	0.1	2,220	10.0
	Rear	2,400	11.0	-	-	-	-	2,400	11.0
	TOTAL	13,800	62.8	8,000	36.2	220	1.0	22,020	100.0
Fatalities	Front	100	24.6	220	55.1	24	6.2	344	85.9
	Side	10	2.8	10	3.6	3	0.8	23	7.2
	Rear	30	6.9	-	-	-	-	30	6.9
	TOTAL	140	34.3	230	58.7	27	7.0	397	100.0
Injuries	Front	10,600	46.3	7,300	32.0	200	0.8	18,100	79.1
	Side	1,300	5.8	900	4.0	20	0.1	2,220	9.9
	Rear	2,500	11.0	-	-	-	-	2,500	11.0
	TOTAL	14,400	63.1	8,200	36.0	220	0.9	22,820	100.0

Table 2-19. Vehicle-Pedalcycle (over 3000 lb) 1985 Projected Accident Summary

		Relative Impact Speed (mph)						TOTAL	
		0-20		20-40		Over 40			
		Number	%	Number	%	Number	%	Number	%
Casualty Accidents	Front	30,300	45.6	21,100	31.7	600	0.9	52,000	78.2
	Side	5,800	8.7	4,000	6.0	100	0.2	9,900	14.9
	Rear	4,600	6.9	-	-	-	-	4,600	6.9
	TOTAL	40,700	61.2	25,100	37.7	700	1.1	66,500	100.0
Fatalities	Front	220	31.8	280	39.6	60	8.2	560	79.6
	Side	40	5.6	50	7.0	10	1.5	100	14.1
	Rear	40	6.3	-	-	-	-	40	6.3
	TOTAL	300	43.7	330	46.6	70	9.7	700	100.0
Injuries	Front	31,500	45.7	21,900	31.7	600	0.8	54,000	78.2
	Side	6,000	8.7	4,100	6.0	70	0.1	10,170	14.8
	Rear	4,800	7.0	-	-	-	-	4,800	7.0
	TOTAL	42,300	61.4	26,000	37.7	670	0.9	68,970	100.0

Table 2-20. Rollover 1985 Projected Accident Summary

	Speed at Rollover (mph)					
	0-30		Over 30		TOTAL	
Under 3000 lb	Number	%	Number	%	Number	%
Casualty Accidents	1,400	3.7	35,500	96.3	36,900	100.0
Fatalities	90	3.7	2,200	96.3	2,290	100.0
Injuries	1,900	3.7	50,200	96.3	52,100	100.0
Over 3000 lb						
Casualty Accidents	1,700	3.7	43,300	96.3	45,000	100.0
Fatalities	100	3.7	2,700	96.3	2,800	100.0
Injuries	2,400	3.7	61,400	96.3	63,800	100.0

2.3.5 Societal Cost and Benefits

To assess the levels of safety performance to be specified for the RSV requires an evaluation method based on quantitative measures. The evaluation procedure used in this study is based on measuring the effects of reducing fatalities and injuries in terms of societal costs. The accrued benefits from the RSV will be expressed in terms of the reduction of societal costs based on projected accident data involving standard vehicles (non-RSV's).

Societal Costs. To make the desired evaluation requires a method for rating the various accident modes so that a ranking of those accident modes may be made in the order of greatest potential payoff. Societal costs, representing a monetary measurement of the direct out-of-pocket and indirect (i.e., pain and suffering) cost to society from injuries and fatalities resulting from automobile accidents, appears to be a reasonable measurement standard to adopt.

A study by NHTSA determined the approximate societal costs associated with several levels of injury severity ranging from no permanent disability to fatal. Table 2-21 summarizes NHTSA's findings.

The societal costs associated with fatalities are comparatively straightforward since only one level of severity exists for this category. The injury category on the other hand ranges in severity from minor (e.g., Category "C" injury) to total disability with a corresponding range in societal costs. NHTSA's study determined an average societal cost of $7,200/incident for the injury category characterizing the 1971 accident environment. This cost reflects an averaged value for all crash modes and velocities and is useful only for top-level comparisons of the various accident modes. For lower level ratings within a given accident mode where considerations for directionality and impact velocity are to be made, new and appropriate averaged societal costs are determined for the injury category to account for differences in the injury severity distribution.

Table 2-21

Societal Costs for Four Levels of Injury Severity

Component	Fatality	Permanent and Total Disability	Partial Disability	No Permanent Disability
Property damage	$ 1,500	$ 1,000	$ 900	$ 700
Hospital costs	700	5,000	1,600	115
Other medical costs	425	2,800	1,200	200
Funeral costs	900	-	-	-
Legal and court costs	3,000	3,000	1,000	150
Wage losses	132,000	139,000	36,000	200
Miscellaneous accident costs	200	200	100	50
Insurance administration	4,700	4,300	4,300	800
Losses to others	1,300	10,000	1,200	100
Employer losses	1,000	1,000	-	-
Community services	7,000	7,000	1,800	-
Pain and suffering	10,000	50,000	10,000	100
Home and family duties, non-work	33,000	35,000	9,000	50
Assets	5,000	2,000	-	-
Total cost per occurrence	200,725	260,300	67,100	2,465

The results of the societal cost calculation (see Figure 2-8) reveal that the total societal cost associated with all passenger vehicle accidents of interest (projected for 1985) amounts to $38.5 billion (B) with the following distribution and ranking of the various accident modes:

		Rank
Vehicle-vehicle	$21.5B	I
Vehicle-pedestrian	$ 5.6B	II
Vehicle-fixed object	$ 6.1B	II
Vehicle-motorcycle	$ 2.1B	III
Rollover	$ 2.08B	III
Vehicle-pedalcycle	$ 1.2B	III

It is apparent from the rankings that vehicle-vehicle impact emerges as the prime contributor to the total societal costs and thus is regarded as the primary impact mode with a significant payoff potential.

Benefit-Cost Analysis Techniques. Benefit-cost analysis is a useful process which enables the decision-maker to choose between alternative solutions. In the case of the RSV program, the alternative solutions are represented by various design configurations containing certain design features which enhance the crashworthiness characteristics of the vehicle.

The term "cost", as in benefit-cost, refers to an incurred penalty measured by a specified loss of some tangible value. In this program, some obvious "costs" are increased curb weight, reduction of performance (e.g., acceleration or mileage), and increasing manufacturing or consumer dollar cost. On the other hand, the term "benefit" refers to a measurable gain of some tangible value attributed to the design effort. The "benefits" of interest to the RSV program are reductions in the number of fatalities and injuries, and a reduction in the amount of incurred societal cost.

Figure 2-8

PASSENGER VEHICLE ACCIDENTS $\bar{C}$ = $38.5B
(1985)

FATALITIES 65,784
INJURIES = $\Sigma NI_i \cdot \eta_{"C"_i} = 3.514 \times 10^6$

SOCIETAL COST:
FATALITIES $13.2B
(INJURIES** $191.6B)
INJURIES*** $25.3B
TOTAL $38.5B

$$\eta^2 = \frac{\sum_{i=1}^{6} NI_i \cdot \eta_{"C"_i} (7200)}{\sum_{i=1}^{6} \bar{C}I_i^* \cdot \eta_{"C"_i}} = \frac{(3.514 \times 10^6)(7.2 \times 10^3)}{109.7 \times 10^9}$$

$\eta^2 = 0.2305$

i = 1	$\bar{C}$ = $21.5B	i = 2	$\bar{C}$ = $5.60B	i = 3	$\bar{C}$ = $6.1B	i = 4	$\bar{C}$ = $2.0B	i = 5	$\bar{C}$ = $1.2B	i = 6	$\bar{C}$ = $2.1B
VEHICLE-VEHICLE		VEHICLE-PEDESTRIAN		VEHICLE-FIXED OBJECT (ON/OFF ROAD)		ROLLOVER		VEHICLE-PEDALCYCLE		VEHICLE-MOTORCYCLE	
FATALITIES	29,739	FATALITIES	11,994	FATALITIES	15,167	FATALITIES	5,140	FATALITIES	1,090	FATALITIES	2,684
INJURIES*	5,262,500	INJURIES*	288,447	INJURIES*	589,801	INJURIES*	115,927	INJURIES*	91,800	INJURIES	93,990
SOCIETAL COST		SOCIETAL COST		SOCIETAL COST		SOCIETAL COST		SOCIETAL COST		SOCIETAL COST	
FATALITIES	$ 5.97B	FATALITIES	$ 2.41B	FATALITIES	$ 3.05B	FATALITIES	$ 1.03B	FATALITIES	$ .22B	FATALITIES	$ .54B
INJURIES**	$134.68	INJURIES**	$ 19.26B	INJURIES**	$ 17.54B	INJURIES**	$ 5.58B	INJURIES**	$ 6.11B	INJURIES**	$ 8.40B
INJURIES***	$ 15.51B	INJURIES***	$ 3.20B	INJURIES***	$ 3.07B	INJURIES***	$ .95B	INJURIES***	$ 1.01B	INJURIES***	$ 1.54B
SCALING FACTORS		SCALING FACTORS		SCALING FACTORS		SCALING FACTORS		SCALING FACTORS		SCALING FACTORS	
$\eta^1_{"C"} = 0.5$		$\eta^1_{"C"} = 0.72$		$\eta^1_{"C"} = 0.76$		$\eta^1_{"C"} = 0.74$		$\eta^1_{"C"} = 0.72$		$\eta^1_{"C"} = 0.8$	
$\eta^2 = 0.2305$		$\eta^2 = 0.2305$		$\eta^2 = 0.2305$		$\eta^2 = 0.2305$		$\eta^2 = 0.2305$		$\eta^2 = 0.2305$	

(1) Scaling factors determined by GRC to remove "C" category injuries.

(2) Scaling factor (Eq. 9) to determine actual societal costs associated with injuries.

*Includes "C" category injuries.
**Includes "C" category injuries, scaling not performed.
***Excludes "C" category injuries, and is scaled.

The approach taken to a benefit-cost analysis for this program consists of evaluating the design effectiveness of an RSV configuration in terms of injuries and fatalities that would result from an accident. In other words, given that an accident occurs, the outcome is expressed by expected-value numbers of injuries and fatalities. These expected values are derived from the baseline accident statistics and consider the frequency distributions of accident types, injuries and fatalities in terms of primary impact direction and relative impact velocity.

The purpose of structuring the analysis on a per-accident benefit and cost basis is to circumvent problems associated with an analysis based on total nationwide benefits and costs. Some of the more obvious problems eliminated by this approach are estimating when the RSV specifications would become effective, how many automobiles at a given time period would be operating with the new safety specifications, and how many accidents would involve safety-type cars.

Therefore, the measure of effectiveness is obtained by assessing the average results of an RSV-configured vehicle being in an accident situation and comparing them with the average results of a non-RSV (baseline) vehicle being in an identical accident situation.

A key feature of the approach is that measures of benefits and costs attributable to a given RSV design configuration are computed in terms of incremental increases to, or decreases from, established baseline values.

The baseline condition established for this program represents a typical subcompact automobile weighing approximately 3000 pounds incorporating all contemporary design features of currently produced cars. The current use rate, effectiveness and reliability of standard safety equipment and structure are represented in the baseline condition.

The benefit-cost analysis is directed to the vehicle-vehicle and vehicle-fixed object accident categories. These two accident categories account for 98% of the casualty accidents, 89% of the fatalities, and 97% of injuries forecast for occupants of motor vehicles in 1985 (see Section 2.3.4, Table 2-9).

The data presented in Tables 2-22 and 2-23 represent the maximum possible improvements that could be achieved by an RSV design over the baseline expected values and are derived in Section 3.3.2, Volume II. Actual improvements affected by realistic design features incorporated by the RSV would be a fraction of the amounts shown in the tables.

An example would be a case where, for the vehicle-vehicle accident category (Table 2-22), the RSV design would be such that fatalities and injuries for frontal impacts are totally eliminated for speeds up to 20 mph and reduced by 50% for the speed range of 20 to 40 mph, with no attainable reductions elsewhere. For this example, the RSV design would offer a benefit of 100% x 20.0% x $2744 + 50% x 17.0% x $2744 = $782 saved per vehicle per accident.

The benefit-cost technique is summarized as follows:

- Benefits

Benefits are derived on a per-accident, per-vehicle basis and represent the improvement offered by the RSV in an accident environment compared with the baseline automobile. Benefits are quantified by calculating the accrued societal costs for the baseline vehicle and RSV and obtaining the cost difference. Hence, the benefit is a measure of incremental improvement.

- Costs

The cost is the quantified penalty incurred to achieve a given benefit. In order to make the RSV more crashworthy than the baseline vehicle, additional safety features are added resulting in some increase in curb weight. Thus, the cost associated with a particular RSV benefit is represented by either the difference in curb weight between the RSV and baseline vehicle, or the actual dollar cost (to the consumer) of the additional safety features.

Impact Direction	Relative Speed (mph)											
	0-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100-110	110-120	120-130
TABLE 2-22. Vehicle-Vehicle Category, Distribution of Maximum Potential Societal Cost Savings Per Accident, for Vehicles under 3000 lb (%)												
Front	20.0	17.0		8.9		4.6	3.1	3.5	2.8	3.2	0.1	1.6
Side	7.9	5.2		1.1	1.0				0.6			
Rear	16.5	2.5	0.2	0.2					0			
Total Potential Societal Cost Savings, C_s, is $2744 per Accident												
TABLE 2-23. Vehicle-Fixed Object Category, Distribution of Maximum Potential Societal Cost Savings Per Accident, for Vehicles under 3000 lb (%)												
Front	9.6	28.7		24.3		7.4	1.3	0.8	0.3			
Side	6.3	7.8		3.5	1.5	1.2	0.9	0.1	-			
Rear	1.0	2.6	0.1	0.1								
Total Potential Societal Cost Savings, C_s, is $14,030 per Accident												

2.3.6 Influence Factors

The accident projections presented in Section 2.3 are considered as baseline data which reflect the effect of vehicle safety features, roadway designs, speed limits, driving habits, and other man-environment-vehicle characteristics (in existence prior to, and through, 1972) on current accident patterns. These system factors and characteristics are dynamic and the extent of their changes in the years leading into the mid-80's will influence the baseline projections.

Six specific factors considered as potential change sources are: the national speed limit, the Federal Motor Vehicle Safety Standards (FMVSS), and four federal highway safety program standards. Table 2-24 summarizes the factors selected for consideration and the accident category which each factor has the potential of modifying.

Table 2-24. Application of Influence Factors

Accident Category	Speed Limit	MVSS 208	HSPS 3 Motorcycle	HSPS 8 Alcohol	HSPS 12 Highway	HSPS 14 Pedestrian
1. Car-Other Vehicle				X	X	
Frontal	X	X				
Side	X	X				
Rear	X					
2. Non-Collision				X	X	
Overturning	X	X				
Other						
3. Car/Pedestrian				X		X
Frontal						
Side						
Rear						
4. Car/Fixed Object				X	X	
Front	X	X				
Side	X	X				
5. Car/Motorcycle				X		
Frontal	X		X			
Side	X		X			
Rear	X		X			
6. Car/Pedalcycle				X	X	
Frontal						
Side						

These factors were selected because: (1) there is some evidence that their implementation in the United States would mofify the accident projections (reduced national speed limit to 55 mph, mandatory helmet usage for motorcyclists, restraint system use, and removal of roadside hazards), or (2) that the accident category incurred societal costs of a sufficiently large magnitude that future effective implementation of the appropriate safety standard (alcohol countermeasures, and pedestrian protection) would be demanded.

In general, each factor can modify an accident projection in one of two ways: (1) by reducing the frequency of occurrence or exposure to, a given accident situation, or (2) by reducing the consequences (trauma) to the persons involved in the accident.

The assessments of influence factors resulted in varying degrees of estimated effectiveness. If a 5% reduction in fatalities is taken as a minimum indication of factor influence, then the following accident categories are affected to the degree shown.

	Factor			
Accident Category	Speed Limit	HSPS #8 Alcohol	HSPS #12 Highway	HSPS #14 Pedestrian
1. Vehicle-Vehicle	13%	10%		
2. Fixed Objects (All)		10%		
Frontal	7%		20%*	
Side	5%		20%*	
3. Rollover	7%	10%		
4. Other		10%		
5. Vehicle-Pedestrian		10%		10%
6. Vehicle-Pedalcycle		10%		
7. Motorcycles (All)	13%**	10%		

*Reduction applicable to on-road events only.

**Reduction applicable to motorcycle to vehicle events only.

Note: Injury reductions are not always the same as those for fatalities; see preceding sections for injury reduction estimates.

The influence factors considered are interrelated and their combined effectivity constitutes an additional influence on baseline projections. Table 2-25 compares the baseline projections and modified projections resulting from combined influence factors.

Table 2-25

Projected Baseline and Modified Accident Summaries

	Fatalities		Injuries	
Accident Category	Baseline	Modified	Baseline	Modified
1. Vehicle-Vehicle	29,700	23,200	5,263,000	4,736,800
2. Fixed-Objects				
On-road	5,700	3,900	376,300	274,100
Off-road	9,400	9,200	214,000	192,600
3. Rollover	5,100	4,300	115,900	97,400
4. Vehicle-Pedestrian	11,800	9,600	283,800	255,400
5. Vehicle-Pedalcycle	1,100	1,000	91,800	82,600
6. Vehicle-Motorcycle*	[2,700]	[2,200]	[94,000]	[84,600]
TOTALS	63,000	51,200	6,343,600	5,638,900

*Included in Vehicle-Vehicle category.

The baseline costs reported in Section 2.3.5 of this report reflect the baseline accident data projected to the 1985 time frame with no influence factors (e.g., enforcement of improved safety standards, lower speed limits, improved roadway designs, etc.) applied. Average societal costs per injury and fatality for each accident mode were determined (using the data of Figure 2-8) and applied to the results in Table 2-25. These results are summarized in Table 2-26.

Table 2-26

Societal Costs Associated with Modified Accident Summaries

Accident Mode	Baseline Societal Costs $ Billions	Modified Societal Costs $ Billions	% Change
Vehicle-Vehicle	21.5	18.6	-13.4
Pedestrian	5.6	4.5	-19.4
Fixed Object	6.1	5.1	-16.4
Rollover	2.0	1.7	-15.0
Pedalcycle	1.2	1.1	- 8.3
Motorcycle	2.1	1.9	- 9.5
TOTAL	38.5	32.9	-14.5

2.3.7 Secondary Accident Modes

In constructing the current national accident profiles, the available data on the constituent accident modes is concerned primarily with the first collision event. In many accidents, a second event may occur (e.g., vehicle fire after first impact, vehicle striking a fixed object or entering a body of water after running off the road) and the consequences of the second event may be more severe to the vehicle occupants than was the initial one.

Vehicle Submergence. The incidence of vehicle submergence and resultant fatalities is estimated to be quite low. The probability of a vehicle submergence accident occurring is 0.2%. Given that a vehicle submergence accident occurs, the probability that the accident would result in a fatality is 8%.

The societal cost due to vehicle submergence fatalities is $0.126 billion. As indicated in Table 2-27, if fatalities caused by vehicle submergence were completely eliminated, the total societal cost would show an insignificant reduction of only 0.43%.

Table 2-27

1985 Projections for Vehicle Submergence and Fire Accident Modes

	Casualty Accidents		Fatalities		Societal Costs	
Accident Mode	Number	Percent	Number	Percent	$ x 10^9	Percent
Submergence	7,880	0.22	630	1.33	0.126	0.43
Fire	16,200	0.45	710	1.50	0.142	0.48
All Other*	3,586,920	99.33	46,060	97.17	29.332	99.09
TOTAL*	3,611,000	100.0	47,400	100.0	29.6	100.0

*Includes the vehicle-vehicle, -fixed object, and rollover accident categories. Excludes the vehicle-pedestrian, -motorcycle, and -pedalcycle accident categories.

Fire in Motor Vehicle Accidents. The incidence of vehicle fires and resultant fatalities also is estimated to be quite low. The probability of a vehicle fire occurring due to a casualty traffic accident is 0.45%. Given that a casualty accident accompanied by a fire occurs, the probability that the accident would result in a fatality due to the fire is 4.4%. Table 2-27 indicates that the societal cost due to fatalities resulting from the vehicle fire accident mode is $0.142. This amounts to only 0.48% of the total societal cost attributed to vehicle occupants killed or injured in accidents.

2.4 VEHICLE CHARACTERIZATION

Based on the projections of the usage and accident environments presented in Sections 2.2 and 2.3 of this summary, a set of characteristics describing a Research Safety Vehicle was developed. As noted in the usage projections, no discrete subenvironments were identified for vehicles operating in the mid-80's. Rather, it is anticipated that vehicle designs will continue to follow the evolutionary patterns and trends experienced in the past. The rate of design evolution, however, is expected to accelerate to meet increasing demands for energy conservation. Therefore, RSV characterizations are influenced primarily by usage and marketing considerations and not by unique or different environments.

The maximum weight of 3,000 pounds for the RSV imposes a number of physical constraints on its design (the number of occupants, overall dimensions, engine size, luggage space, etc.). However, these constraints do not preclude the development of an acceptable and producible RSV which may ultimately prove to be more compatible with the total environmental and resource limitations in the mid-80's than would the larger cars. Usage projections indicate that a 4-passenger sedan would adequately satisfy the average occupancy needs for all identified travel purposes. Therefore, one RSV concept is characterized to fulfill this usage. It is recognized that while population forecasts indicate a continuing decline in the size of the average household, there will be families whose size exceeds the average; the car requirements to satisfy these needs can be fulfilled by the mid-80 car models in the weight classes above 3,000 pounds.

Usage forecasts indicate a continuation of the current trend toward low occupancy, short trip length use for a significant percentage of work-related and family business travel. This suggests that a potential market will exist for a small, utility car whose primary function would be to satisfy this usage in a more economical manner than would the 4-passenger RSV concept or the larger cars. This consideration led to the characterization of a second RSV concept, a 2-passenger utility car.

In effect, usage projections and considerations imply a continuation of the present multi-car household patterns, with the single car household choosing the larger car to fulfill all trip purposes. There are no indications that the drivers of the second (or third) car restrict its use in any way, consequently, the second RSV concept of the utility car will be exposed to the same traffic and accident environment as is the first concept.

The subsequent parts of this section present the characterization descriptors of both concepts where required, and common descriptors where RSV size is not a factor. To the extent possible, characterization is associated with need as determined from current assessments and projections, primarily with those associated with the accident environment. State of the art considerations are treated in terms of the mid-80's, where such developments can be anticipated as a result of current work. In many instances, a number of alternative approaches can satisfy the characterization of specific RSV subsystems; the alternatives are listed with the final selection to be made by the car designer.

Where quantitative descriptions are used in characterization, these are considered to be first approximations based on current passenger car designs and performance and on engineering estimates. Similarly, some characterization descriptions are equivalent to specifications; a clear distinction between the two is always evident. In all cases, descriptors, in either quantitative or qualitative terms, are subject to change when future design analyses will provide a valid basis for establishing firm values.

2.4.1 Vehicle Configuration

Two RSV concepts are characterized based on projected usage considerations, one concept is based on a 4-passenger family sedan, and the second, on a 2-passenger utility sedan. For each concept, a number of variations in configuration are possible and these are described in terms of their relative merits.

4-Passenger RSV Sedan

The external configuration of this concept is shown in Figure 2-9, as a 2-door sedan to accommodate two 95th percentile males in the front seats and two 50th percentile males or three children in the rear seat. The basic dimensions shown in the figure for this concept are based on a front engine, front wheel drive power train arrangement. Conceptual styling lines were based on characterization considerations of minimizing air drag, reducing frontal hazards to pedestrians and bicyclists, providing acceptable sight lines, as well as eye appeal.

Figure 2-10 depicts the internal arrangement of the driver and adult passenger and the volume allocations for the riding and handling systems. Driver seating, controls and displays, visual aids, and restraints are to accommodate the range from a 5th percentile female to a 95th percentile male; as an objective, equal performance of all these subsystems for the range of drivers is sought. The driver position shown in Figure 2-10 is that of a 95th percentile male with a conventional hand and foot control arrangement and an adjustable seat to accommodate the 5th percentile female and improve access to the rear seat entry and exit. This arrangement has limitations in terms of providing equal sight lines and positioning of hand and feet on controls for the driver size range. An alternative arrangement would have movable hand and foot controls and a vertically adjustable seat to enable the drivers to position themselves for the maximum field of view and preferred control positions. With driver seat adjustment limited to vertical movement, access to the rear seat from the driver's door may be limited.

The interior arrangement of front seat area is designed to provide a maximum of occupant ride-down distance for effective performance of any selected restraint system and protective padding. A center console is placed between the front seats to provide an additional area for control or accessory placement and for lateral restraint. The longitudinal length of the console provides a potential location for the fuel tank in an area where structural integrity should be high under all crash modes. A conventional instrument panel layout is anticipated, enhanced by the incorporation of a diagnostic warning system for safety critical functions (e.g., brakes, tires).

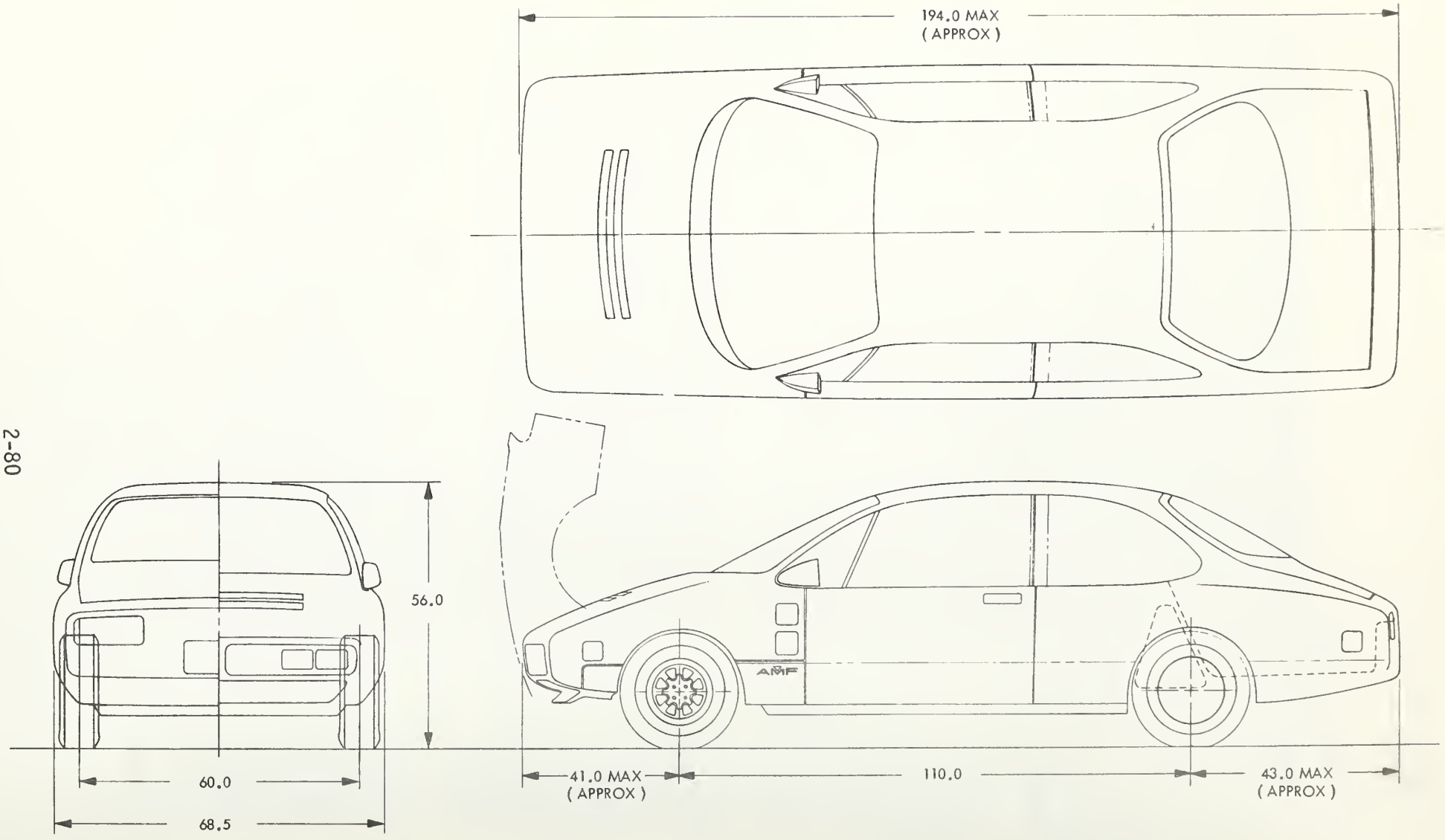


Figure 2-9. Four Passenger RSV Sedan - External Configuration (Front Engine)

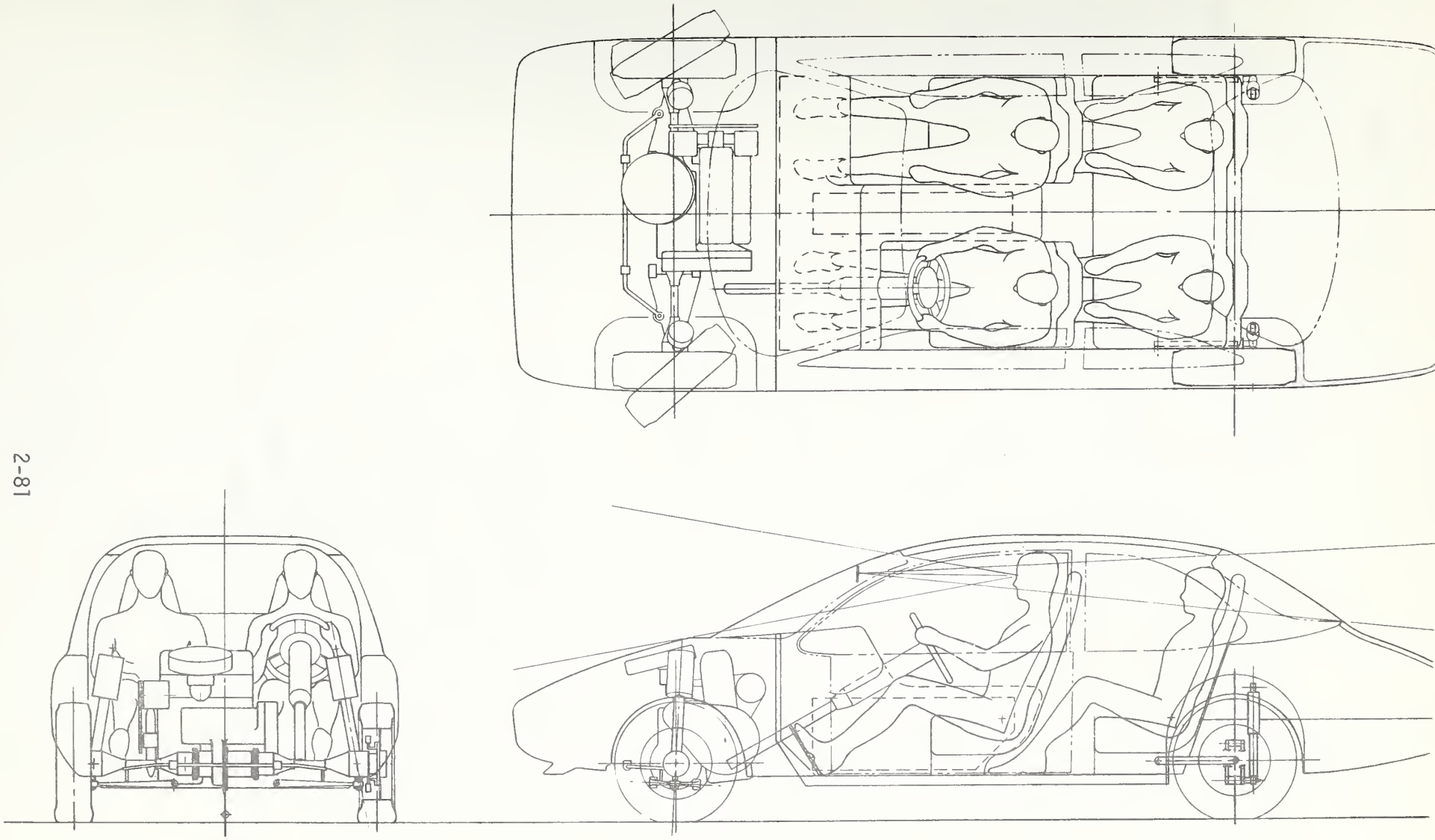


Figure 2-10. Four Passenger RSV Sedan - Internal Configuration

An alternative arrangement of a 4-passenger RSV is one driven by a rear engine, rear wheel drive. Its internal arrangement would preserve the driver and occupant features provided in the front engine, front wheel drive concept. The characterization considerations for both drive arrangements in terms of general external and internal configurations are essentially the same. The merit of the rear engine concept lies in the relatively free uncluttered front end volume for maximizing energy absorbing performance in frontal impacts. In addition to alternative engine placements, a 4-door, 4-passenger sedan concept is an optional body configuration which is characterized by more acceptable access for the rear seat occupants.

The curb weight of either concept will be limited to 2,500 to 3,000 pounds range; a feasible weight range for an RSV based on the ESV's developed by off-shore manufacturers. Curb weight as used herein is SAE's definition, the standard car as specified plus water, oil, gasoline; less optional equipment, accessories, and luggage. The standard car is defined as having the smaller of the engines it was designed to accept, a manual transmission, and a heating and ventilating system. Larger engines, automatic transmissions, and an air conditioning system are considered as optional equipment.

2-Passenger RSV Sedan

This vehicle can be best characterized functionally as a utility car providing essential travel needs (work-related, family business, educational, civic, and religious) at the least cost. In its anticipated role as a second car in multi-car households, its occupant comfort features would be less than that of the 4-passenger RSV sedan, but acceptable for the relatively short trip distances it would be exposed to.

Figure 2-11 depicts the external configuration of this RSV concept and Figure 2-12, the internal arrangement resulting from a front engine, front wheel drive power train. The spatial layout of the driver and right front

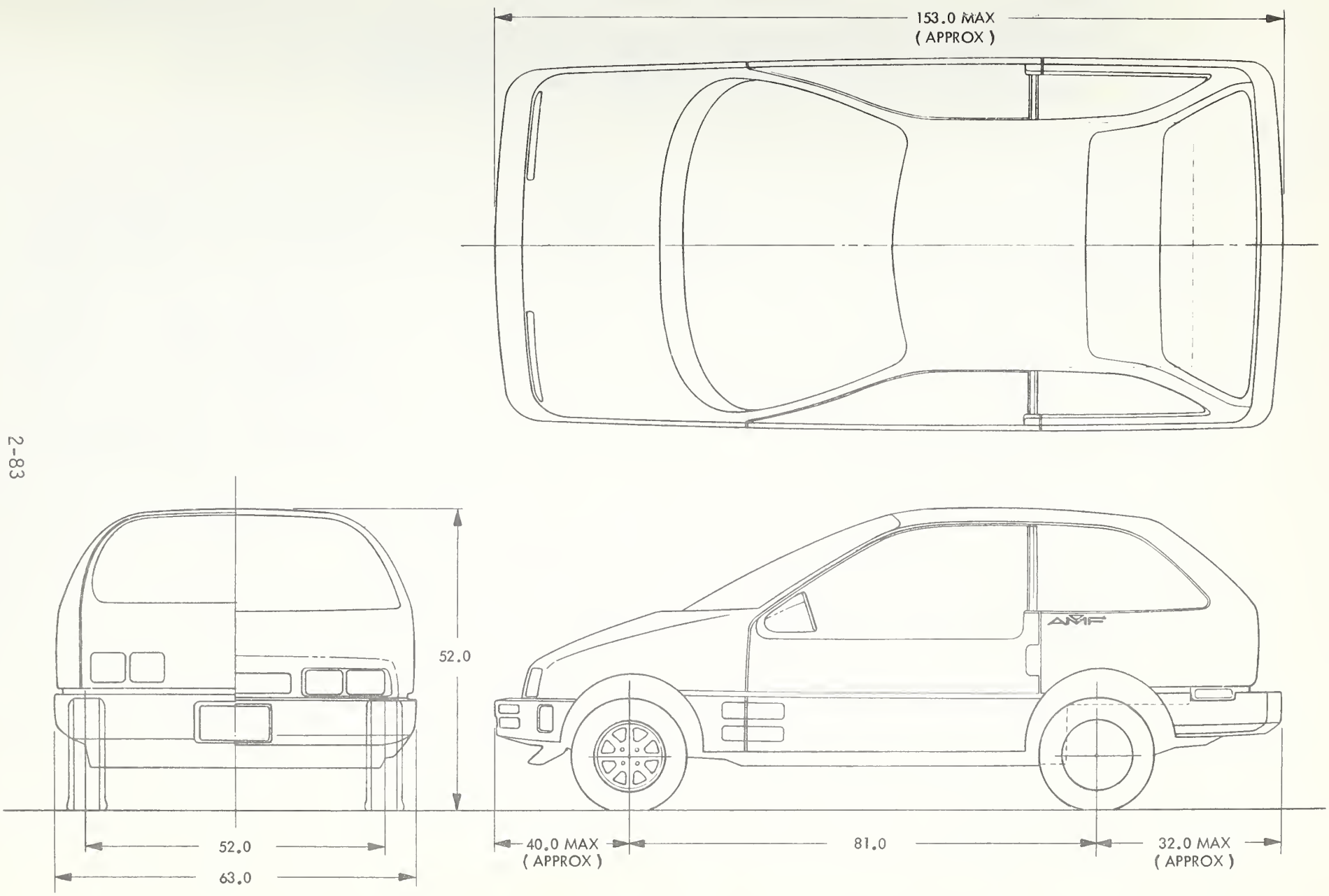


Figure 2-11. Two Passenger RSV Sedan - External Configuration

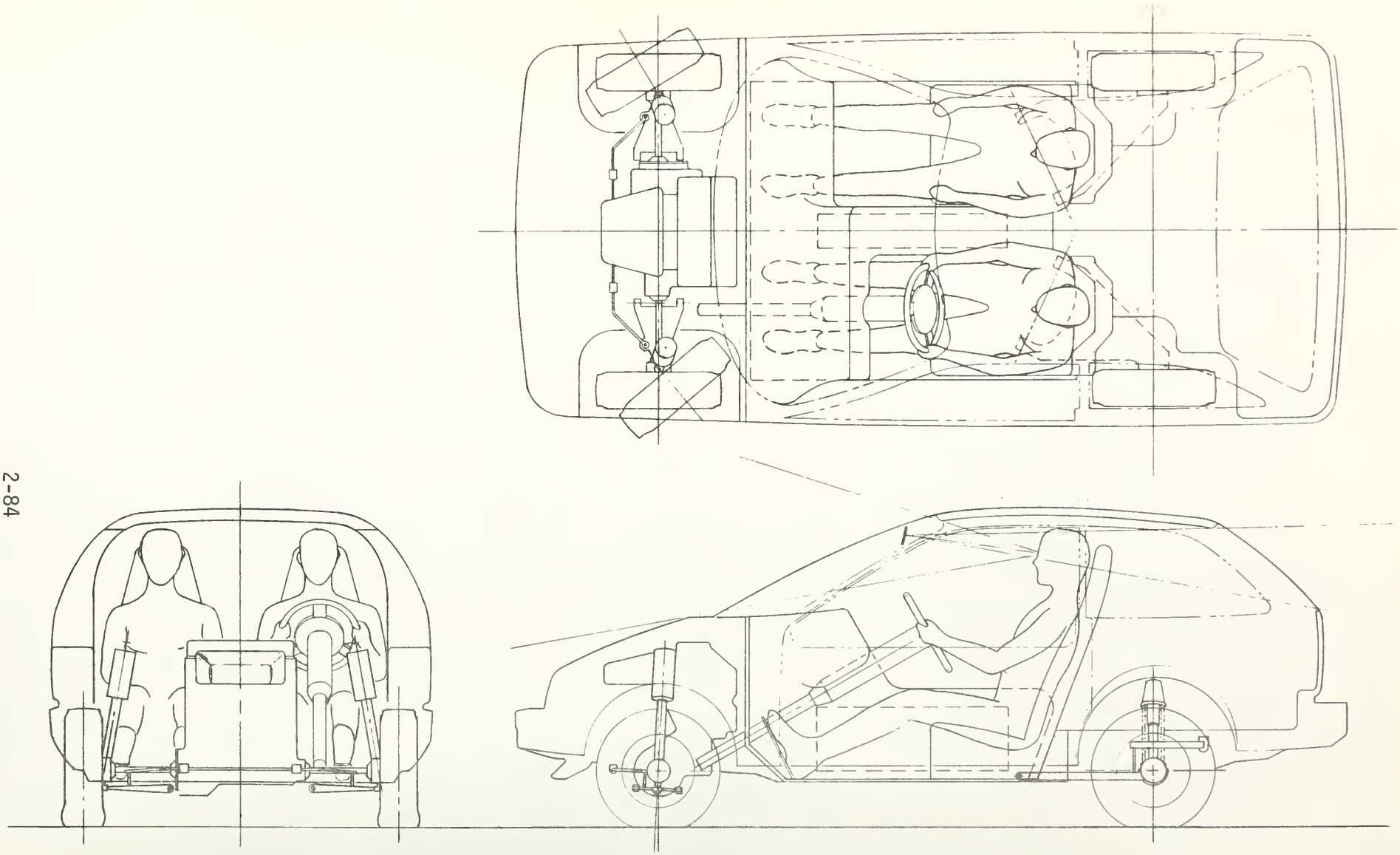


Figure 2-12. Two Passenger RSV Sedan - Internal Configuration

occupant, of the controls, console, etc., are the same as that provided in the 4-passenger sedan concept to provide equivalent performance of safety related systems in the interior.

Alternative configurations of this concept are also feasible. The basic 2-passenger sedan can be modeled in a station wagon or van version, as shown in Figure 2-13, and either the wagon or van can be converted in a pick-up model. The alternatives presented are to indicate that an RSV concept need not be limited to one specific model but rather that concepts should be shown to be capable of satisfying any marketing demands.

The estimated curb weights of the 2-passenger sedan shown in Figures 2-11 and 2-12 would fall in the 2,000 to 2,500 pound range.

It should be noted that the styling configuration presented for the RSV concepts are primarily to assist in describing characterizations rather than preliminary body lines which would have been subjected to some degree of analyses, interface compatibility and other tradeoff studies.

The characteristics of the systems and hardware elements that comprise the two RSV concepts are presented in the succeeding parts of this section.

2.4.2 Safety Performance Characteristics

While all elements of a vehicle system interact in providing safe performance in normal driving and accident avoidance situations and protective performance in accident situations, certain vehicle elements and subsystems are vital to safety. The characteristics of these are presented in the following descriptions; the characteristics of the functional subsystems are presented in the next subsection.

Visibility, Lighting, and Signaling

The driver's field of view is an important factor in the safe operation of the automobile. Ideally, the automobile driver should be provided with an unobstructed horizontal view of 360 degrees with commensurate

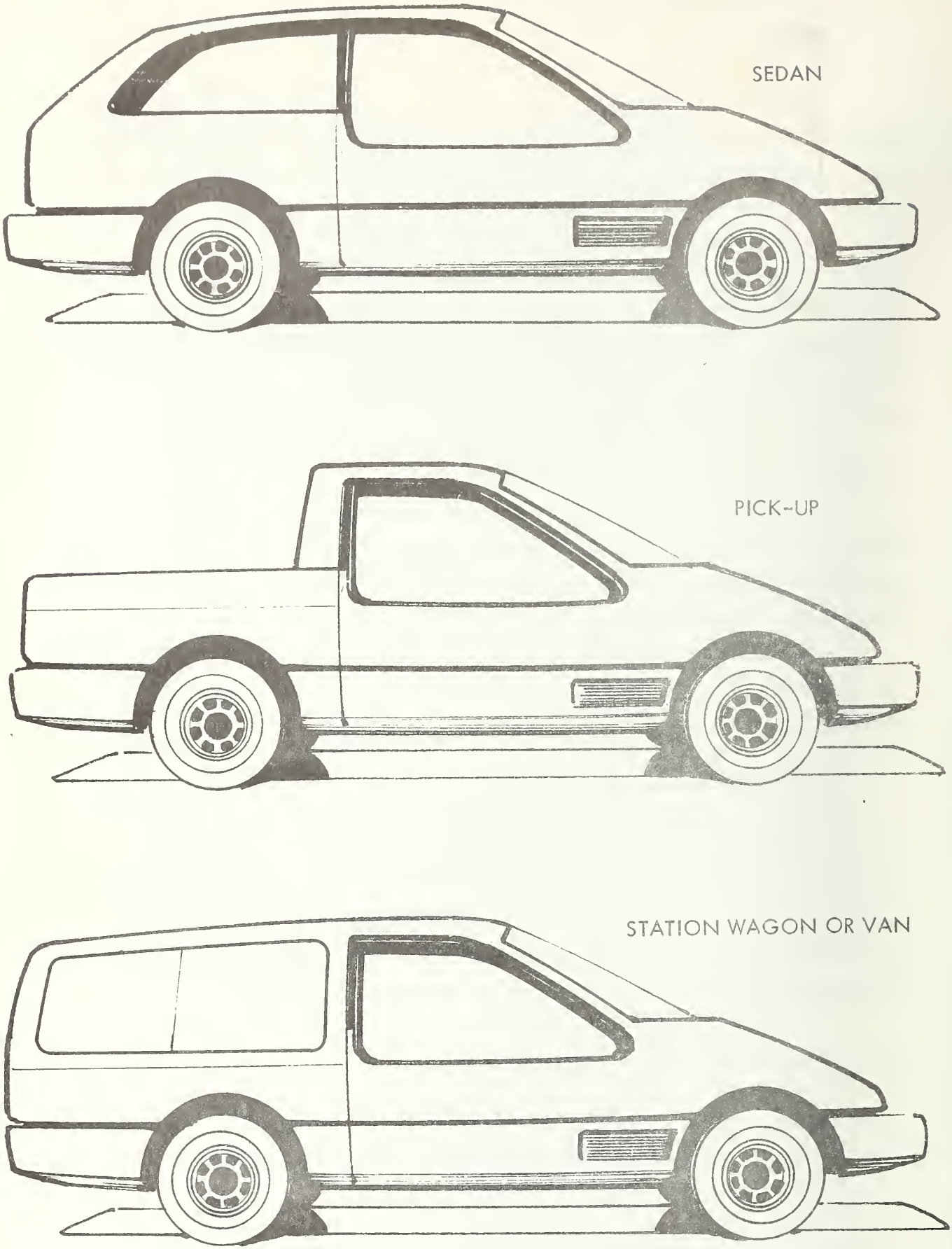


Figure 2-13 Model Variations - Two Passenger Sedan

vertical viewing angles around the vehicle. However, this maximum field of view is unattainable without degrading the automobile structure or incurring added costs for vision improvement devices. The accident statistics and literature examined in the course of this study provided no insight into inadequate fields of view as a causative factor in accidents nor what minimum viewing fields should be. Therefore, it is difficult to assess the cost of accidents caused by viewing deficiencies and consequently, to properly estimate the cost/benefit ratios of any improved viewing systems. Any device added to improve visibility becomes difficult to justify, and in particular, those that are more costly (i.e., rear periscopes and radar sensing devices) in terms of initial installed cost or operating upkeep (maintaining the reliability of the visual aid).

The characteristic of the RSV driver's viewing field is a minimum cost system with a maximum of usable visibility. The elements of the system include a maximum of glazed area within a high roof line, a low belt line and pillars that meet structural rather than styling criteria, and a rear mirror array. The array would consist of an internal mirror and external right and left side mirrors.

To maintain critical glazed areas at effective cleanliness levels, windshield and backlight washers are provided. A washer nozzle located in the wiper blade would insure proper delivery of cleaning fluid to the window surface. The wiper blades would be stored in a protected area when not in use to minimize deterioration from weather factors.

The windshield and backlight are defogged by appropriately heated air circulated near the glass area or by electrical heater elements located in the glass.

The characteristics of the lighting and signaling systems are common to both RSV concepts since they will be exposed to essentially the same usage and accident environments.

Accident data and accident studies provide no insight into current lighting and signaling systems performance as a prime or contributing causative factor. The accident projections indicate a continuation of current trends of higher fatality and injury rates during the night, and of higher night rates on rural roads than on urban roads. These conditions suggest that headlights, in particular, may play some causative role in night accidents especially at higher speeds and in rural areas. Increased road illumination with improved beam patterns would enhance forward road visibility with a minimal penalty in either cost or weight.

Current U.S. dual-beam sealed lamps have 6000 candela available as a low beam to provide night visibility of 200 to 250 feet and a high beam of 7500 candela intensity to provide visibility of 400 to 450 feet. European cars use much brighter headlights, with total intensity of 300,000 candela to provide 600 to 700 foot night visibility.

General Motors has proposed several new headlight systems which consist of rectangular shaped lamps with two or three beams of higher intensities as shown below.

	5" x 7-1/2" Rectangular 2 Lamp System	4" x 6-1/2" Rectangular 4 Lamp System	
	2 beam	2 beam	3 beam
Low Beam	20,000	20,000	20,000
Mid-Beam	-	-	60,000
High Beam	80,000	80,000	155,000

Of the three systems, the 4-lamp, 3-beam system provides distinct advantages over current headlight systems in terms of increased forward illumination and the addition of the mid-beam provides additional illumination (over the low beam) of the right side road edge while cutting off left side to avoid glare to on-coming drivers. This system is characterized for the

4-passenger RSV sedan, while space limitations in the smaller utility RSV and its intended usage indicate the headlight characteristics of the 2-lamp, 2-beam are appropriate to it.

Studies and tests by General Motors have demonstrated that daytime front running lights indicate vehicle presence and help in speed and distance determination of the other car in passing, intersection, and turning maneuvers. The required intensity of 2000 to 5000 candela for this type of daytime front running light can be obtained by using the upper beam filaments at a reduced voltage of 6 to 8 volts in the 2-lamp, 2-beam system and by an added filament in the 4-lamp systems. Since a potential though undefined benefit is to be derived from simple changes to the front headlight system, front daytime running lights are also characterized for both RSV concepts.

Various rear lighting and signaling configurations have been suggested to improve driver response of the following car; however, a common industry standard on signal functions, colors, and placements remains to be established.

Based on an evaluation of related studies in signaling, the RSV rear lighting arrangement is characterized by separate rear lamps for presence indication, stop and turn signals with both low and high rear body locations, and a decelerating signal. The two sets of stop and turn signals provide for desirable redundancy in the event of a lamp failure. Although a deceleration signal has not proven its value as a result of wide use, the relatively high incidence of injury-producing rear end accidents suggests that it would be of value in high density traffic to warn following drivers of speed reductions in downstream vehicles. The color coding for the characterized lamps is the following:

- Stop - red
- Presence - green
- Turn - amber
- Deceleration - amber

Riding and Handling Systems

Prior to characterizing the riding and handling systems treated in this section (braking, steering, front and rear suspensions, and front and rear wheels/tires), the influence of the total vehicle configuration on these systems and their performance is discussed and appropriate characterizations made.

Weight and Weight Distribution. The vehicle's weight and weight distribution influence the performance and the design of interacting systems like suspension, braking, steering, etc. Automobiles designed and manufactured in the U.S. have characteristic "understeering" yaw response which provides inherent vehicle stability up to higher vehicle speeds. Because of the RSV's lower weights and smaller wheel bases, they will exhibit an "understeer" response to a lesser degree than do larger vehicles. Since fore and aft weight distribution is one important factor which influences this yaw response behavior, the characteristic objective will be to hold fore/aft curb weight distribution within the range of 60/40 to 45/55 percent. This range of weight distribution will ensure that the desired safe yaw response can be designed into RSV's without degrading ride comfort or braking performance. The characterized weight distribution limits for the 2- and 4-passenger RSV weight ranges are shown in the table that follows.

CHARACTERIZED WEIGHT DISTRIBUTION LIMITS

	2-Passenger RSV		4-Passenger RSV	
	Curb Weight (lbs)		Curb Weight (lbs)	
Configuration Limits	2000 lbs	2500 lbs	2500 lbs	3000 lbs
Front Heavy (Front/rear, 60/40)	1200/800	1500/1000	1500/1000	1800/1200
Rear Heavy (Front/rear, 45/55)	900/1100	1125/1375	1125/1375	1350/1650

Load Conditions. The vehicle load conditions will influence both performance specifications and system designs; therefore, consideration is given to minimum and maximum vehicle loads based on vehicle occupancy factors. The characteristic load condition for the RSV's, established on the basis of their occupancy and luggage allowance, are presented in the table that follows.

RSV WEIGHTS UNDER LIMIT LOADS*

	2-Passenger RSV		4-Passenger RSV	
	Curb Weight (lbs)		Curb Weight (lbs)	
Load Condition	2000 lbs	2500 lbs	2500 lbs	3000 lbs
Driver Only Load	2245	2745	2745	3245
Full Design Load	2490	2990	3380	3880

*95th percentile male passenger - 215 lbs + 30 lbs of luggage
50th percentile male passenger - 165 lbs + 30 lbs of luggage

Braking System Performance. The characterizations of the RSV braking system performance are as follows:

1. Straight Line Stopping. The RSV carrying the full design load and the driver only load, and traveling on a level road at 60 mph will stop without two wheel lock-up on any axle while remaining in a lane 12 feet wide. The stopping distance will be in the range of 150 to 172 feet from an initial speed of 60 mph. This stopping performance is equivalent to an average deceleration capability of between 0.7 and 0.8 g. Pedal effort allowed for straight line braking will be within the envelope bounded by the maximum gain-minimum effort line of 0.21 g/lb and the minimum gain-maximum effort line of 0.0085 g/lb.

2. Braking on a Curve. The RSV with a full design load and a driver only load will be capable of decelerating to a stop within 73 to 86 feet, without wheel lock-up and deviation from a 12 foot lane, from a steady state speed of 40 mph on a radius of curvature path that produces 0.3 g lateral acceleration. This deceleration capability will be in a range of 0.62 to 0.73 g's. The steering effort allowed during braking on a curve will be a steering input of up to 180 degrees at a rate not to exceed 500 degrees per second. The allowable pedal effort for braking on a curve will be the same as that characterized for straight line braking.

3. Braking on a Split Coefficient Surface. The RSV with a full design load and a driver only load will be capable of stopping from a speed of 40 mph within 118 to 152 feet, when traveling on a split coefficient surface with skid numbers of 75 and 25. This performance is equivalent to deceleration capability range of 0.35 to 0.45 g's.

4. Service Brakes Under Partial Failure Condition. Two failure modes are provided for: (1) booster failure, and (2) leakage type failure of a pressure component in the service brake system. The straight line stopping capability of the RSV from an initial speed of 60 mph will be 300 ft for booster failure (0.4 g) and 388 ft for front system failure (0.31 g).

5. Parking Brake Performance. The RSV, at curb weight and when fully loaded, will hold on a 30% grade in the uphill and downhill directions. The actuation effort for hand-controlled operation will be less than 90 pounds, and for foot-controlled operation less than 125 pounds.

6. New Developments. Advanced state of the art developments, such as anti-skid or side proportioning systems, have not been characterized for the RSV concepts because a need for them was not demonstrated based on the study findings.

7. Diagnostic Elements. Lack of maintenance and poor mechanical condition of vehicles have been cited as accident causative factors; therefore, diagnostic elements in the vehicle are characterized to make the driver aware of needed critical maintenance or repair. In addition to diagnostic elements in the vehicle, external diagnostic systems to examine the functional condition of various vehicle systems are being studied by the industry and a series of standards are being developed to assure interchangeability of diagnostic hookups. The RSV will conform with such developments once they are identified and accepted.

8. Safety Critical Components. Safety critical items like brake lines, brake fluids and brake pads, will conform with the applicable industry accepted practices, SAE standards, and FMVSS.

Braking Configuration. Both RSV concepts (2- and 4-passengers) will have 4-wheel disc brakes. Since these vehicles will be used for short distance trips in stop and go traffic, 4-wheel disc brakes will provide superior fade-proof performance.

The brake pads will be visible and will include embedded material which will provide an audible squeak signal when the pads are worn below an acceptable level. Diagnostic warning indicators on the RSV's will monitor brake fluid level and incipient brake failure (i.e., detect and indicate degradation failure before brake application).

Power assist for the brakes will not be necessary for the 2-passenger RSV and may not be necessary for the 4-passenger RSV; a detailed design analysis is required to determine the need for a power assist for the 4-passenger RSV.

In characterizing the braking system, it was decided that anti-lock features could not, at this point in the program, be justified, and in particular for the 2-passenger RSV. In order to stay within implied

marketing constraints, the added weight and cost imposed on the small vehicle category by anti-lock features may require compromising more beneficial crashworthiness and occupant protection features.

The braking performance of a vehicle on split coefficient surfaces can be improved by the incorporation of negative steering geometry. The result of this geometry is a restoring torque under braking which counteracts the tendency to swerve when the two front wheels are on different surfaces. This steering feature is characterized for both RSV concepts.

To comprensate for the transfer of weight from the rear to the front wheels during braking, the brake cylinder pressure in these wheels is varied by the addition to a pressure modulating valve in the rear brake line.

A split master cylinder and dual circuit braking system is used to assure at least partial braking capability under emergency considerations. Various front to rear, side to side, and diagonal dual circuit arrangements are possible. A specific arrangement is not characterized; the candidates require analyses of effectiveness, partial failure performance, and complexity prior to any final selection for the RSV.

Steering System Response. The RSV steering response is characterized for three performance categories. Each category and its performance characteristics are described below.

1. Steady State Yaw Response. Steady state yaw response is an indication of how the vehicle will behave under the action of a constant external side force under a steady state of pavement, speed, and driver control conditions. The parameter for steady state yaw response is yaw gain, defined as yaw rate divided by front wheel angle. The control parameters are speed and lateral accelerations. In Figure 2-14, the response characteristic is shown as a function of yaw gain x wheelbase to account for different RSV wheelbase dimensions. The figure shows two main zones of steering

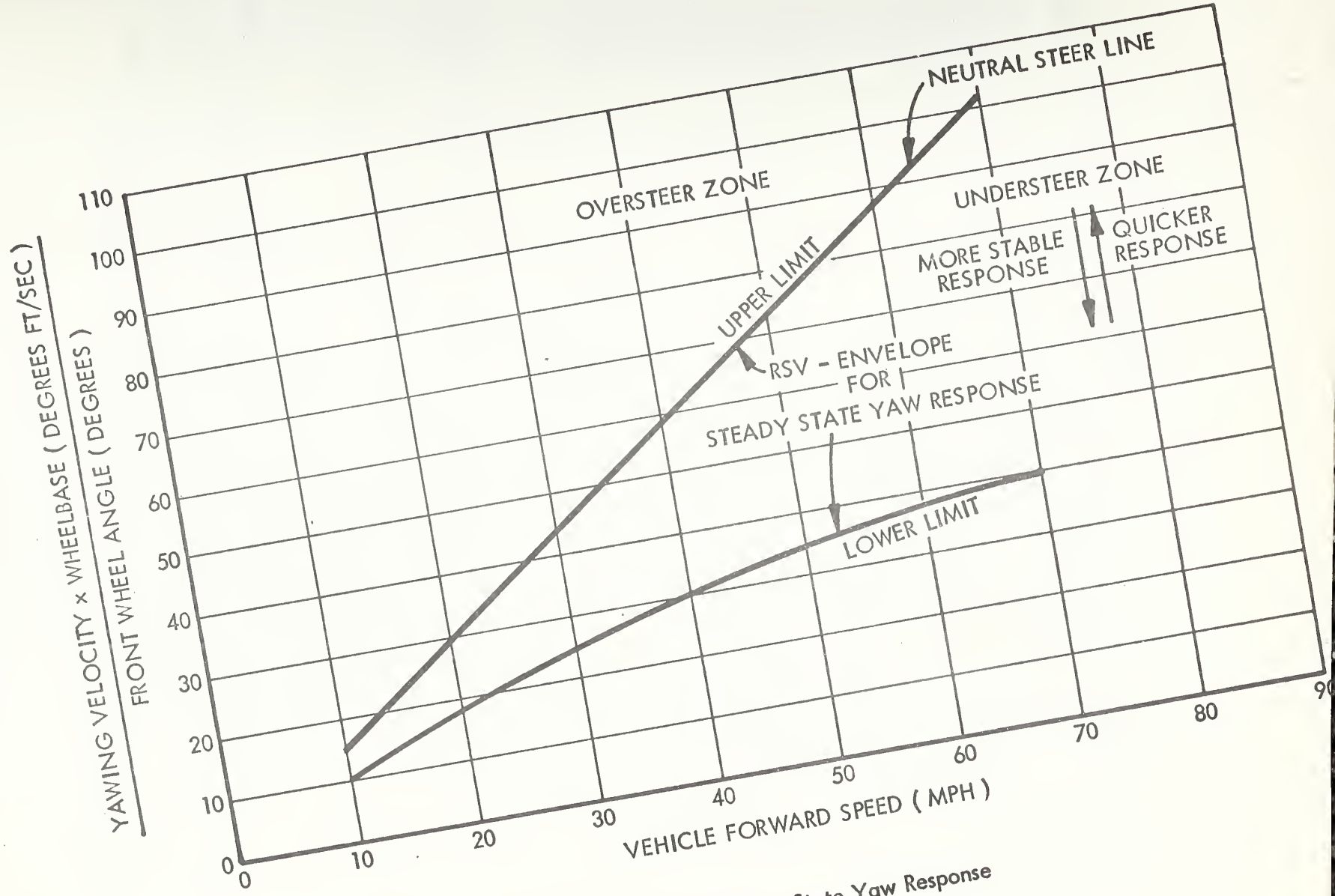


Figure 2-14 RSV Steady State Yaw Response

response divided by a neutral steer line. In the understeer zone, the vehicle is basically stable. In understeer zone, as the yaw response approaches the neutral steer line, the vehicle stability is reduced but its yaw response to steering input is quicker. In the oversteering zone, the vehicle has a finite critical speed above which it can go into an unstable mode, but overall, the vehicle response to steering input is faster. The RSV, because of its smaller size, will have a steady state yaw response characteristic near neutral steer line. The desired characteristic envelope for the RSV, shown in Figure 2-14, will provide quick yaw response without instability.

2. Transient Yaw Response. The basic understeer/oversteer characteristics are equally applicable to the response from a transient steering action as in a rapid lane change or steering around an obstacle. In such cases, loss of control can occur in a fraction of a second. The transient yaw response goal for the RSV is to control the transient yaw gain "overshoot" and dampen it within reasonable time to a steady state value. Figure 2-15 shows upper and lower limits for 70 mph and 25 mph speeds. For these transient yaw responses, the steady state lateral acceleration value is 0.4 g.

3. Returnability. Returnability is a measure of the self-correcting capability of a vehicle's steering subsystem in a transition from a circular path to straight ahead path. The responses to be avoided are:

a. Extreme sluggishness.

b. Extremely hard kickback of steering.

c. Oscillatory transient response.

A smooth, well damped and fairly quick transition from one steady state (curved path) to other steady state (straight ahead) is the characteristic of returnability performance. This performance can be attained by a suitable selection of steering system which is compatible with suspension geometry and tire characteristics.

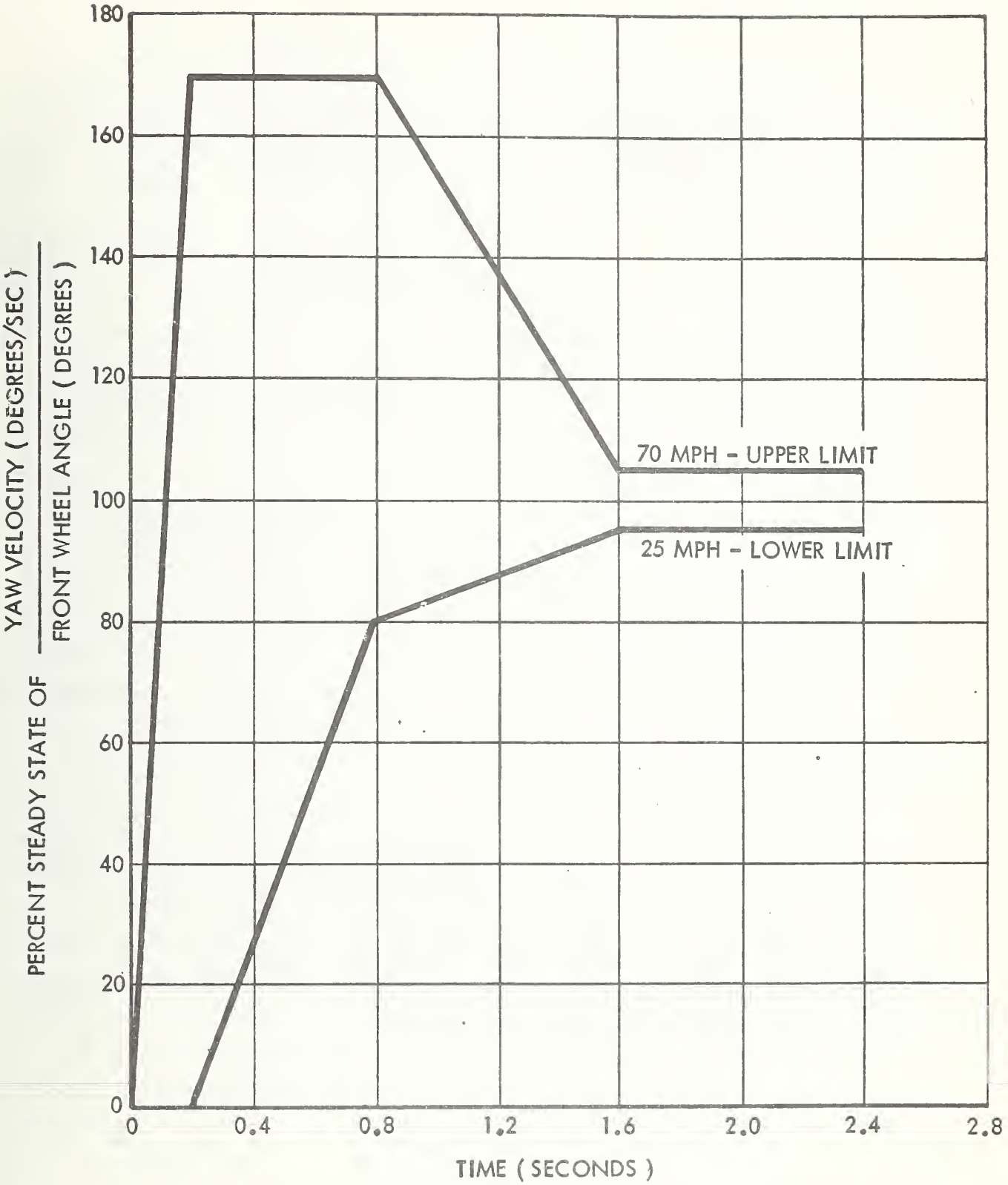


Figure 2-15. RSV Transient Yaw Response

One performance characteristic that was considered is that resulting from the inclusion of some type of adaptive or autopilot steering to enable the vehicle to overcome road irregularities and occasional side winds. The need for and benefits derived from such a feature were not obvious.

Configuration. A rack and pinion steering system is characterized for both RSV concepts. This device is relatively small, lightweight, and provides good road feel, and is considered to be an appropriate system for cars under 3,000 pounds. Variable cam steering is an acceptable alternative system, particularly for the larger RSV in a high front wheel loading configuration. Variable steering would provide higher mechanical advantage at high steering wheel displacements (usually made in low speed maneuvers) and a low mechanical advantage with better control for the smaller steering displacements made in straight ahead driving. Manual steering, without any power assist, is selected to minimize weight; however, the front loading conditions for the 4-passenger RSV concept will require analyses to verify the adequacy of manual steering for this vehicle.

Both RSV concepts are characterized by relatively small turning circle diameters, 24 to 28 feet, to enhance maneuvering in city traffic and in parallel parking.

Handling Response, Lateral Acceleration Capability. Accident cause analyses indicate that improper tire inflation, resulting from both neglect and tire gage inaccuracies, is a contributory cause of accidents. To minimize the effects of such conditions, the RSV is characterized by a lateral acceleration capability under various front/rear combinations of inflation pressures as shown in the table that follows.

MINIMUM LATERAL ACCELERATION PERFORMANCE

Surface	Tire Pressure	Lateral Accelerations (g) (Fixed Control)
Dry Concrete or Asphalt	Design Value	0.60
	120% design value	0.60
	80% design value	0.55
	120% design, front 80% design, rear	0.63
	80% design, front 120% design, rear	0.59
Wet Concrete or Asphalt	Design Value	Dry Surface Performance Dry Skid No./Wet Skid No.

Control at Breakaway Capability. The control at breakaway performance of a vehicle is a measure of its capability to recover from a hazardous turning situation without braking. The RSV's are characterized by this capability when turning in two fairly sharp curves, 100 feet and 225 feet radius respectively, after losing lateral grip (traction) at a maximum lateral acceleration level of approximately 0.6 g's.

Directional Stability. The RSV's will demonstrate a directional stability at speeds of 50 mph under the cross wind and pavement irregularity conditions established in the referenced procedures. Causal accident data have not indicated any need for upgrading this performance level.

Because of the small size of the RSV's, manual steering is indicated and hence, the requirement for steering control sensitivity will be modified. With manual steering, the torque required to cause a yaw rate of 2°/sec will be above 5 in-lbs applied steadily at the rim of the standard wheel. The purpose of this performance level is to assure a minimum level of effort required to prevent inadvertent steering errors and yet, keep the steering control fairly effortless.

Overturning Immunity. Small vehicles are more susceptible to overturning because of their geometry. A stability factor, a geometric measure of a car's resistance to overturning, is defined by Sager and Brink as T/2H, where T is the average of front and rear track widths, and H is the height of center of gravity above ground level. The RSV design goal will be to lower the center of gravity of the RSV as much as practical and to achieve a stability factor of at least 1.5 (the average of representative current vehicles of different sizes).

The desired overturning immunity characteristics for the RSV are as follows:

- Be immune to overturning on a level, paved track under a series of steering and braking maneuvers up to its maximum speed limit.
- Be capable of negotiating a slalom course at forward speeds of 50 mph.
- Be capable of executing drastic steer and brake maneuvers from initial speeds of 50 and 60 mph.

Front and Rear Suspension Systems. The attainment of good overall suspension system performance is more of a design challenge for smaller RSV type vehicles than for larger vehicles if the desired ride comfort levels, cornering capability, and overturning immunity are to be obtained.

The preceding Figure 2-10 depicts the volume allocations to ride and handling systems and the 4-wheel independent suspension system characterized for the RSV's. As one the suspension system candidates, Figure 2-10 shows a MacPherson strut for the front end and a transverse leaf spring for the rear end. The advantage of the MacPherson strut is the elimination of the upper control link which allows the engine to be placed transversely. The rear transverse leaf spring fixed in the center, serves the dual purpose of providing vertical spring action and partial transverse rigidity to the suspension system.

As alternatives to these arrangements are transverse torsion bars providing suspension for the front end and semi-trailing arms with coil springs providing suspension for the rear end.

The candidate suspension arrangements for the 2-passenger RSV concept are a front end with MacPherson strut suspension and a rear end with semi-trailing arm and coil springs.

The preceding descriptions indicate the various possible arrangements of basic suspension systems and system elements. Several other candidate elements, including rubber springs, longitudinal torsion bars, viscous fluid springs, and Hydragas springs, are available for evaluation prior to a final selection for RSV use.

Since the suspension system interacts with the braking and steering systems and the mass properties of the vehicle, a balanced design of all these systems is required to achieve the characterized performance levels for safe riding and handling. The suspension system to be selected is therefore characterized by the following features:

- Geometry that provides negative steering to improve braking on split coefficient surfaces.
- Anti-dive provisions to control this motion during braking.
- Controlled roll center height, controlled front and rear roll steer, and where necessary, stabilizer bars to bound the suspension roll stiffness. These characteristics are provided to enhance safe cornering performance.

Wheels and Tires. Radial tires with run-flat devices, providing a run-flat capability of 100 miles at 45 mph, are selected for the RSV. Anticipated advances in radial tire design (fiberglass cord, improved wet road performance) indicate this tire is highly appropriate for the small RSV.

Tire blowout problems will be partly taken care of by run-flat devices, but keeping tire inflation pressures at a correct level remains a problem. Several small warning devices are being offered to monitor the tire pressures and give the driver a warning if pressure goes below a certain level. These devices require further evaluation of their benefits before they are specified as an RSV "need" item.

Crashworthiness

Vehicle crashworthiness by definition is the ability of a passenger vehicle to reasonably protect its occupants from death and serious injury while exposed to the hazards encountered during driving on public roadways. For this study, the term vehicle crashworthiness is extended to the protection of those crash victims who are impacted by the vehicle exterior (i.e., pedestrians and cyclists). Reasonable protection, as used here, infers an acceptable balance between occupant protection and other important constraints on the vehicle design (e.g., cost, weight, fuel economy, emissions, etc.

Six crash modes were recognized in this study as being representative of the 1985 crash environment. The projected accident statistics for these crash modes are summarized in Table 2-28. This data clearly shows the importance of the car-car accident mode since this mode alone accounts for approximately 57% of the total societal cost associated with all of the accident modes considered. The following ranking of the accident modes (in descending order of importance) is suggested by Table 2-28:

Car-car	I
Car-fixed object	II
Car-pedestrian	III
Car-motorcycle	IV
Rollover	V
Pedalcycle	VI

Table 2-28

Accident Statistic Summary, Projected 1985 Crash Environment

Accident Mode	Impact Direction	Baseline Societal Costs $ Billions	Modified Societal Costs $ Billions
Car-Car		21.5	18.6
	Front	15.1	13.0
	Side	3.1	2.7
	Rear	3.3	2.9
Pedestrian		5.6	4.5
	Front	5.1	4.1
	Side	.3	.2
	Rear	.2	.2
Fixed-Object		6.1	5.1
	Front	5.0	4.2
	Side	.9	.7
	Rear	.2	.2
Rollover		2.0	1.7
Car-Pedalcycle		1.2	1.1
	Front	1.0	.8
	Side	.2	.2
	Rear	.1	.1
Car-Motorcycle		2.1	1.9
	Front	1.2	1.1
	Side	.8	.7
	Rear	.1	.1

It should be noted that the respective rankings remain the same for the baseline projections of costs and for the baseline projections modified by potential effectiveness of legislation, highway safety programs, and other factors enhancing driving safety in the next decade.

Naturally, when an attempt is made to efficiently allocate or budget available resources for crashworthiness, a set of priorities must be established in harmony with the potential benefits to be gained (i.e., in accordance with the relative importance of the accident modes as indicated in the ranking on page 2-102).

The following discussions address the various subsystems affecting vehicle crashworthiness to derive the desirable characteristics for each subsystem which can later be tested for cost and weight effectiveness.

Vehicle Interior. The accident modes most likely to introduce injuries to the occupants within the vehicle interior are the following:

- Car-car
- Car-fixed object
- Rollover

Table 2-28 shows that these accident modes account for approximately 80% of the societal costs associated for all accident modes considered, thus indicating the importance of vehicle interior design for crashworthiness. Various studies of interior design for injury-producing sources have been conducted; the following potential impact areas have been identified as the most hazardous to the occupant during a given collision encounter:

- Steering wheel assembly
- Instrument panel
- Front windshield
- Side glazing
- Interior structure
  - Windshield header
  - "A", "B", "C" pillars
  - Doors
  - Roof
- Seats

The RSV interior is therefore characterized by a well integrated system that will restrain the motion of the occupant(s) during impact without exceeding the human tolerance limits for injury. This implies that the interior (including steering wheel assembly, instrument panel,

etc.) functions together with a primary seat restraint system in protecting the occupant during impact. For example, the steering wheel assembly is characterized by an ability to either move freely away from the occupant with little resistance (to offer maximum stroke for the primary restraint) or to assist in restraining the occupant by having appropriate crush characteristics during its collapse. Similarly, other contactable surfaces are provided with surface crush (or breakaway) characteristics that offer an acceptable interaction with the occupant(s).

Of the six accident modes studied, the car to car accident mode was estimated to incur approximately 57% of the total societal costs. This mode encompasses the three collision configurations (or directions): front, side and rear. In frontal impacts, 95% of the associated societal costs fall below a closing velocity of 100 mph. Therefore, the RSV is characterized by protecting its occupants in frontal impacts with a 100 mph closing speed (50 mph equivalent barrier speed). This value is judged to be a reasonable upper limit. A recent study by Carter indicates that it is currently within the state of the art to design a restraint system to accommodate this impact speed (the achievement of this level of protection is, of course, dependent on the interior vehicle configuration and available stroking distance for the occupants). The test results of the preceding ESV program also indicate that it is currently feasible to design a vehicle so that a restraint system can be made effective at this high impact speed. In the car to car side impact configuration, the RSV is characterized by occupant protection up to approximately 40 mph relative impact speed, the level of the current state of the art for this impact configuration based on ESV findings. For rear end car to car collisions, protection up to 40 mph relative impact speed is characterized as being within the state of the art.

The dependency of societal costs on impact speed for a car impacting fixed objects indicates that this mode is more severe (here the relative

impact speed is the equivalent barrier speed) than the car-car mode, and appears to be the constraining mode for occupant protection. However, Table 2-28 shows that the estimated societal cost for the fixed object mode is less than one-third of the societal cost estimated for car to car mode. Based on this consideration, it seems reasonable to confine the occupant protection levels to reflect the car to car impact requirements, and to accommodate the crashworthiness requirements for the fixed object accident as a "spin-off" of these protection levels.

The most severe accident mode for interior protection is probably the rollover mode. Fortunately, this impact mode does not occur nearly as frequently as the car-car mode and has a total estimated societal cost of less than 1/10 of the associated cost for car-car accidents. Protection in a 30 mph rollover is characterized as a reasonable goal for the crashworthiness of the RSV interior.

A final consideration in interior crashworthiness is ingress-egress, the ease with which an individual can get into (or out of) the vehicle, after an accident. An interior design, well integrated with the vehicle structure to provide suitable means of escape following a collision and to assist those who are attempting to remove the victim(s) following impact, is a characteristic of the RSV. The primary feature is structural integrity of the interior components and the doors and door latching and locking mechanisms. In the 2-door, 4-passenger RSV concept, the front seats withstand all impact loadings without jamming their fold-down locks; the fold-down locks are placed so they are readily accessible to rear seat passengers for quick actuation in emergency situations. In a 4-door configuration, these provisions are not applicable. However, the rear doors provide a direct ingress and egress path.

Vehicle Body Structure. The vehicle body structure works jointly with the vehicle interior in protecting the occupant(s) against death or serious injury during a collision. The body structure serves two extremely important functions in vehicle crashworthiness: (1) it limits the passenger compartment acceleration so that a restraint system can function effectively, and (2) it limits the occupant compartment intrusion to preserve survival space for the occupant(s).

The same set of impact conditions are characterized for the body structural design as those previously discussed for the interior design since both the structure and vehicle interior are to satisfy the same crashworthiness objectives, namely, to provide enhanced protection for the vehicle occupants as efficiently and economically as possible. Consequently, the discussions in the previous section pertaining to the characteristic impact configurations apply here.

The performance requirements for the body structure, however, are somewhat different than that for the interior and consequently will require a different set of characteristics. In addition to the previously noted functions, the structure has one further requirement, to minimize aggressive actions to other vehicles during impact.

From previous ESV work, it appears that reasonable restraint performance can be achieved for peak vehicle accelerations of 40 g's and 20 g's for front (and rear) and side impacts respectively. In addition, the same research effort demonstrated that general intrusion limits of three inches maximum can be satisfied at relatively high impact speeds with nominal weight penalties. Similar structural characteristics are set for the RSV with the possibility of relaxing the intrusion requirements somewhat to allow greater intrusion in non-critical areas. The desired structural characteristics for the RSV thus include the following:

- Passenger Compartment Acceleration Limits

Front/rear	40 g's
Side	20 g's

- Passenger Compartment Intrusion

Critical areas	3 inches
Non-critical areas	As justified by technical considerations (must not create sharp protruding surfaces into the compartment).

Additional characteristics required of a crashworthy body structure stem from the fact that most real world accident configurations are not "ideal" (i.e., some degree of obliquity is involved) and consequently, a practical crashworthy vehicle structure must possess suitable crush characteristics with energy absorption capability to accommodate these non-ideal impact situations.

Although not necessarily safety related, a desirable feature of the RSV structure is low impact speed protection for the body structure to minimize costly repairs resulting from relatively minor accidents which frequently occur at low speeds in congested areas (i.e., city streets, parking lots, etc.). Based on the current state of the art in bumper system design, a 5 mph (equivalent barrier speed) system is characterized for the RSV. This level of protection is a reasonable one and incurs only a nominal weight penalty.

Vehicle Body Exterior. Of the six accident modes considered in this study, those involving exterior vehicle impact with a pedestrian, a motorcyclist, or a pedalcyclist pose the greatest threat the the crash victim(s). The characterized RSV exterior configuration is one which minimizes the hazard associated with exterior impacts. The suggested cost effective approach to accomplish this is simply to streamline the vehicle so that all sharp protruding surfaces located in the vicinity of the point of impact are eliminated or are de-hostilized, contacted surfaces absorb impact energy, and further to shape the front structure so that the tendency is for the

victim to be thrown away from the vehicle rather than be captured and forced beneath the vehicle. These design techniques are complementary to aerodynamic drag reduction considerations important for fuel economy. Properly shaping the vehicle structure for controlling the victim's trajectory should prove to be effective, especially for speed impacts above 20 to 30 mph, since only a fraction of the total available energy will be imparted to the victim.

Occupant Restraints

The RSV is characterized by an occupant restraint system which includes those devices in the vehicle interior that are designed to mitigate the impact forces acting on the occupant(s) during a crash event. The following types of restraints are recognized as candidates for use in the RSV:

- Passive deployable restraint
- Passive deployable restraint and active lap belt
- Active torso and/or lap belt
- Passive torso belt and passive knee restraint
- Active torso belt and passive knee restraint

The specific type or combinations of restraint systems to be used in the RSV is dependent on the cost effectiveness of each design when subjected to the projected accident environment. Therefore, only generalized characteristics of the restraint system are presented.

The restraint system, characteristically, is capable of providing protection for the occupants while the RSV is undergoing front, side, rear, and rollover impacts. Further, the system minimizes bodily contact with the vehicle interior. This implies ample room to stroke the restraint, without the occupant encountering harsh obstructions, for the full range of impact speeds and of occupant sizes (5th percentile female to 95th percentile male). The occupant restraint is characterized as providing a minimum level of protection for the full occupant size range as specified in FMVSS 208.

2.4.3 Functional Performance Characteristics

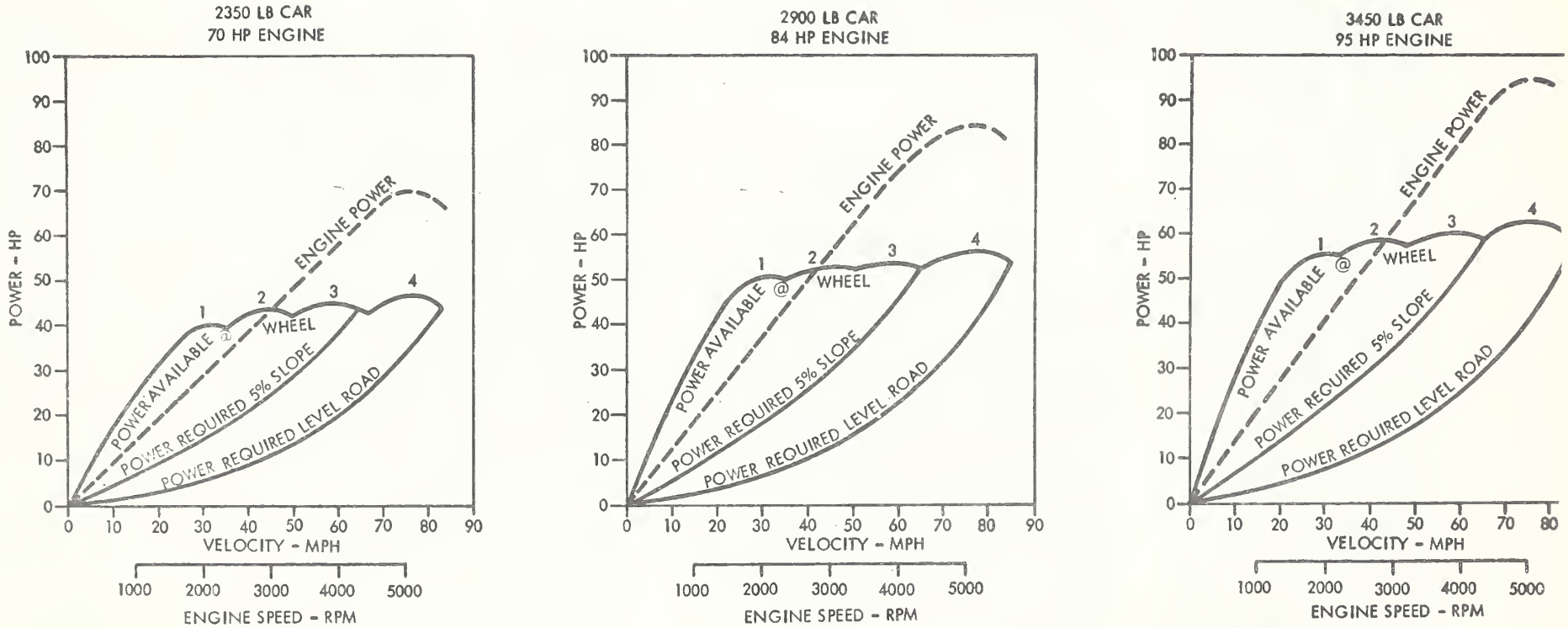
Propulsion (Power Train) System

Since two RSV configurations have been characterized, the description of the propulsion system appropriate to either RSV is presented in parametric terms with vehicle weight as the variable.

The characteristics of the propulsion system are determined by a number of factors including acceleration capability, fuel economy, and the weight and size of the system. These factors directly or indirectly influence safety performance, total vehicle weight, and the first and operating costs of the vehicle.

In order to keep the size and weight of the system to a minimum value, a minimum acceptable performance level (in terms of acceleration) is desired ("Hot" performance is considered incompatible with the projected availability of resources in the mid-80's). In terms of performance, good acceleration in the low speed portion of the vehicle speed range is considered desirable.

A series of propulsion system characteristics for vehicles having test weights of 2350, 2900 and 3450 pounds (equivalent to the estimated curb weight range of the two RSV concepts) were calculated. Figure 2-16 shows the road power needed to obtain a specified performance level for the three weights. The power available curves are based on a 4-speed transmission and a power characteristic that is obtained from current automotive engines. The piston engine is not now selected as the RSV power source, however, the power shown as available from such an engine and transmission is characterized for the RSV. The power required curve shows the amount of power needed at each speed the vehicle attains for the specified performance. The curve indicated as level road power is the power needed to keep the vehicle at constant speed. The difference between the level road power and the power available curve is the acceleration power, that is, the pow-



Road Power Available and Required for Three Test Weight Cars of Equal Acceleration Performance

Figure 2-16

needed to accelerate the vehicle throughout the total speed range. The power available curves in these cases are positioned by selection of power gear ratios to give high acceleration at low speeds and also to limit the top speed of the vehicle. The second road power curve denotes the power required to negotiate a five percent slope. The performance and power requirements for the vehicle weight considered are summarized as follows:

Vehicle curb weight, lbs	2000	2500	3000
Vehicle test weight, lbs	2350	2900	3450
Max. engine power, hp	70	84	95
Max. power available at wheels, hp	46	56	63
Max. speed, mph	83	85	85
Time to accelerate to 30 mph, sec	6.5	6.5	6.5
Time to accelerate to 40 mph, sec	9.6	9.4	9.5
Time to accelerate to 50 mph, sec	13.6	13.4	13.8
Time to accelerate from 30 mph to 60 mph, sec	12.8	12.6	13.3
Max. speed on 5% slope, mph	64	65	64

These performance values with their respective power plant outputs are characterized as minimum acceptable performance. Higher powered engines could be installed with better performance as options. For example, increasing the power for the 2900 pound test weight vehicle from 84 to 104 hp increases the acceleration as follows:

Acceleration from mph	Time, seconds
0-30	5.3
0-40	7.6
0-50	10.7
30-60	9.5

Also, increasing the power for the 3450 lb test weight vehicle from 95 to 137 hp increases the acceleration for various speed ranges as follows:

Speed Range, mph	Time, seconds
0-30	4.2
0-40	6.2
0-50	8.9
30-60	8.1

These power increases would result in increases in the size and weight of the power plant and fuel consumption. The increased fuel requirements depends on whether the extra power is used for performance. If a comparison is made of the lower and higher powered cars driven on the same driving cycle, then the fuel economy does not suffer as much. It is estimated that a 10% increase in engine size only increases fuel consumption by only 2% when the car is driven on the federal cycle. However, a higher performance vehicle will be driven at higher accelerations, thereby increasing fuel consumption to much higher values and such a characteristic is deemed to be inappropriate to the objectives of the RSV program.

Accessories

To achieve a minimum weight and to conserve fuel, the RSV is characterized with a minimum of accessories. Provision for optional accessories are made but these are not installed in the "standard" version of the RSV.

Heating, ventilating and defrosting or defogging units are provided; air conditioning is an optional accessory, not installed. Ventilation is of the flow-through type without the necessity of opening windows. Heating is obtained by using engine waste heat as in current practice. Defrosting and defogging utilizes the heat from the heating system; electrical heating by resistance elements located in the glass is an alternative system.

A radio is provided to make broadcasted weather, traffic conditions, and other road information available to the driver.

Courtesy lighting is used to illuminate the car interior and doorways when entering or exiting the car and provide a light source for map reading.

2.4.4 Use of RSV Characterizations

The introduction to Section 2.4, Vehicle Characterization, noted the overall traffic environment projected for the mid-1980's did not identify any essentially discrete traffic sub-environments which would make the use of a single, common automobile concept impractical. Rather, the projections anticipate an accelerated evolution of current production passenger car designs into mid-80 models that conform with national needs to conserve energy, material, and economic resources and to preserve environmental air quality. The characterized RSV's, therefore, reflect two basic automobile concepts (and the permissible subsystems within the concepts) that are appropriate for the projected usage and traffic environments.

Based on the usage projections, the 4-passenger RSV concept was considered to have the larger market and use potential in the mid-1980's and was therefore selected as the basic type of automobile for which a set of recommended performance specifications were developed. These specifications are the subject of the next section, Section 2.5.

The specific features characterized for the 4-passenger RSV concept will provide a starting point for subsequent design and development of an RSV that complies with recommended specifications.

2.5 PERFORMANCE SPECIFICATION

The recommended specifications for the RSV are presented in their entirety. Findings of the usage and accident studies, summarized in Sections 2.2 and 2.3, provide the basic justification for the specified levels of protective performance. Preliminary analyses, indicating the feasibility of attaining the specified performance levels, are presented in Section 5.2, Volume III. The technical contents of this study precludes the presentation of a meaningful synopsis appropriate to an executive summary.

TECHNICAL SPECIFICATION
U.S. RESEARCH SAFETY VEHICLE (RSV)

1.0 GENERAL DESIGN REQUIREMENTS

1.1 OBJECTIVES

The usage environment projected for the mid-80's indicates that the automobile will still be the predominant mode of transportation in the United States, and automotive designs, because of their high capital investments and long lead times, will continue to develop in an evolutionary manner. However, this design evolution will be constrained by national energy conservation programs, either voluntary or legislated, anticipated to be in effect throughout the 1980 decade.

The present U.S. growth rate for energy is 4 to 5 percent annually. In order to bring energy demand into balance with the domestic energy supply over the next decade, an estimated 50% reduction in the annual growth rate is required while new energy sources are being developed. From 1950 through 1970, the imbalance was made up primarily by crude oil imports from the mid-East at prices which showed virtually no increases in this period and which were below North American source prices. Since 1973, and primarily since October 1973, the basic prices of oil imports have increased to

approximately seven times the earlier levels. The consequences of the pricing policies of oil exporting countries are reflected not only in a doubling of gasoline prices but in universal price increases in all sectors of the energy-intensive U.S. economy.

The implications of demand limiting national energy policies on the RSV and its contemporaries in the mid-80's include:

- Lowered utilization of energy intensive materials and processes in production automobiles.
- Lowered fuel consumption.
- Increased operational life.

here the parent ESV program had the primary objective and goal of providing high levels of crashworthiness and occupant protection for the ESV weight class, the RSV objectives and goals must encompass the additional constraint of resource limitations. Accordingly, the specifications that are presented in the subsequent sections address the total RSV system in terms of safety performance and resource conservation considerations.

1.2 VEHICLE DESCRIPTION

The general external and interior configurations of the vehicle shall conform with the following requirements:

Body Style	Sedan, 2- or 4-door
Size Classification	Subcompact
Curb Weight*	3,000 pounds max.

*As defined in Part 571.3(b), Motor Vehicle Safety Standards, United States Code of Federal Regulations.

Capacity — 4 passengers

The car shall accommodate, as a minimum, the following physical size range of occupants in the seating positions indicated:

Front Compartment:	5th percentile female through 95th percentile male.
Rear Compartment:	5th percentile female through 50th percentile male.

Exterior Dimensions

The exterior car and body dimensions shall be compatible with the specified body style, capacity, and curb weight.

The manufacturer shall specify these dimensions in the appropriate sections of MVMA-40A Specification Form, Passenger Car.

Interior Dimensions

The interior car and body dimensions shall be compatible with the specified body style, capacity, occupant size and curb weight.

The manufacturer shall specify these dimensions in the appropriate sections of MVMA-40A Specification Form, Passenger Car.

Luggage Compartment

The usable luggage capacity shall be compatible with the specified body style, capacity, and curb weight.

The manufacturer shall specify compartment dimensions in the appropriate section of MVMA-40A Specification Form, Passenger Car.

2.0 SAFETY PERFORMANCE REQUIREMENTS

The specifications for safety performance address all the vehicle systems and subsystems that contribute to the RSV's accident avoidance capabilities, and in the event of an accident, to the protection of its occupants and any other involved participants. While each system and subsystem is specified in terms of its functional performance in avoiding accidents or mitigating accident consequences, there is the implied requirement for balanced performance of the total system in all its functions.

In those instances where the specified performance requirements or conditions for measuring performance differ from existing or proposed FMVSS's, the differences are attributable to the usage and accident environments projected for the mid-80's and to the research data required on a production vehicle concept that is to operate in those environments. Where there are differences, this specification shall take precedence.

2.1 VEHICLE HANDLING AND STABILITY SYSTEMS

The specifications, under this heading, establish the accident avoidance performance of the systems associated with the vehicle's driving dynamics. Unless otherwise specified, all performance tests involving vehicle dynamics will be conducted on a surface with a skid number of 70 to 80 and by a skilled test driver. The vehicle shall be loaded to simulate a front occupancy load consisting of 95th percentile males in the driver and right passenger positions and a luggage allowance of 30 lbs each in the trunk compartment, and its tires inflated to the specified pressure.

These specifications define the test conditions, values, curve shapes, limiting envelopes, etc., for determining compliance with the safety specifications related to the vehicle's dynamic performance.

2.1.1 Braking Performance

Service Brakes

Straight Line Braking. The vehicle, in both a 100% of rated load condition and in a lightly loaded* condition, shall be capable of decelerating to a stop in a distance of 160 feet (24.2 ft/sec^2) from a steady state speed of 88 ft/sec (60 mph). This performance shall be accomplished without two

---

*Lightly loaded, per FMVSS 105a, is defined as the unloaded vehicle weight plus 300 pounds (including driver and instrumentation).

wheels on any axle locking up and without deviation from a 12 foot wide lane. In performance tests involving the 100% of rated load and the lightly loaded conditions, the loads shall be distributed in the vehicle so as to simulate the weight and location of occupants and their luggage as specified in 1.2, Vehicle Description.

Braking in a Turn. With the same load conditions as above, the vehicle shall be capable of decelerating to a stop in a distance of 80 feet (21.5 ft/sec^2) without two wheels on any axle locking up or deviating from a 12 foot wide lane from a steady state speed of 58.7 ft/sec (40 mph) on a radius of 357' (producing 0.3 g lateral acceleration). Steering inputs up to 180° are allowed with the rate of steering input not to exceed 500 deg/sec.

In accomplishing the performance specified above, the pedal force shall fall between lines 1 and 2 on Figure I.

Braking on Split-Coefficient Surface. With the same load conditions as in straight line braking, the vehicle shall be capable of decelerating to a stop from a steady state speed of 58.7 ft/sec (40 mph), within a distance of 134 feet (12.88 ft/sec^2) when traveling on a split coefficient surface with skid numbers of 80 and 25. The performance is to be accomplished while remaining in the 12 foot wide lane.

In addition, as a minimum, the service brake system will ensure braking performance in accordance with the values specified in Table I, where:

E = Brake system efficiency

F = Tire factor

R = Brake rating

M = Wet to dry performance rating.

Table I. Braking Performance

	E	F	R	M
Normal	80.0	1.25	100.0	-
Single System Failure	60.0	1.25	75.0	-
Booster Failure	64.0	1.25	80.0	-
Wet Pavement	90.0	1.15	103.5	0.95
Minimum Load	90.0	1.25	112.5	-

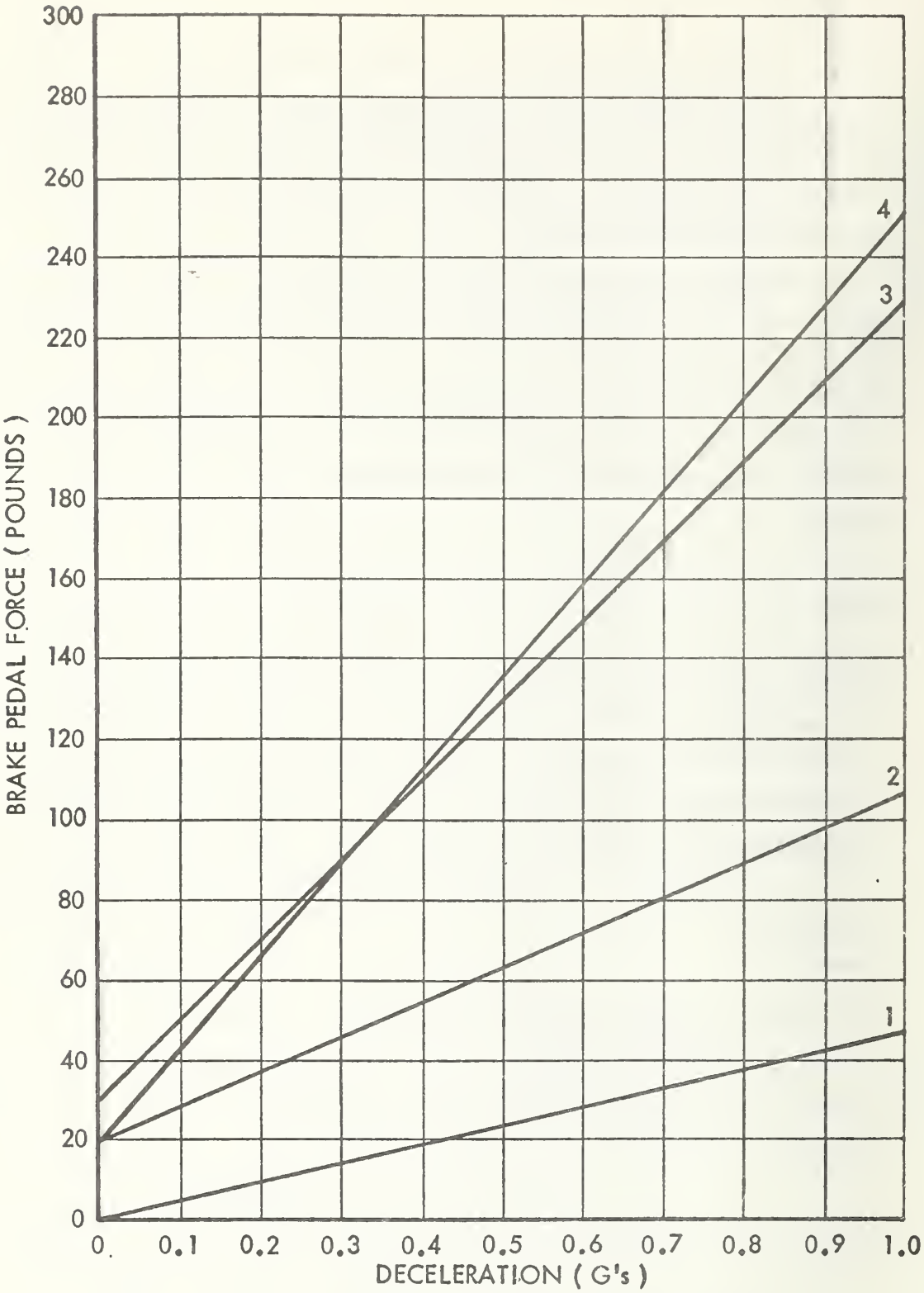


Figure I. Vehicle Deceleration versus Brake Pedal Force

The procedures for calculating the above factors are established in HSRI report, "A Procedure for Evaluating Vehicle Braking Performance" (DOT HS 800 628).

Emergency Brakes

In the event of a booster failure or a leakage type failure of a pressure component of the service brake system, other than a structural failure of a master cylinder, the remaining portion of the service brake system shall continue to operate. With the vehicle at 100% rated load or lightly loaded and a booster failure or partial single failure induced into the system, the pedal pressure shall fall between lines 1 and 3 and lines 1 and 4 respectively in Figure I. Vehicle stopping distances from a steady state speed of 88 ft/sec (60 mph) shall be as follows:

Failure	Stopping Distance
Booster Failure	200 ft. 0.60 g at 150 lbs pedal force
Single System Failure	214 ft. 0.56 g at 150 lbs pedal force

Heat and Water Fade Performance

The heat and water fade recovery performance of the brake system shall be 10% above that specified in FMVSS 105a, January 1, 1976.

Parking Brake

The vehicle, at curb weight and when fully loaded, using a friction type mechanical brake, shall be capable of holding on a 30% grade in the forward and reverse directions. Brake actuation effort shall be less than 90 pounds for a hand-operated system and 125 lbs for a foot-operated system.

Vehicle Jacking

If run-flat devices are used in the vehicle tires, no vehicle jack is required; however, safe jacking points or areas shall be defined for maintenance purposes. If run-flat devices are not provided, a spare tire and wheel,

and a safe, convenient jack shall be furnished. The minimum acceptable criteria for the jacking subsystem have been published as a proposed FMVSS (Reference 35 FR 17055, November 5, 1970).

2.1.2 Steering

Yaw Response

In response to a steering input for which the lateral acceleration is 0.4 g (± 0.02), the vehicle must:

- Maintain a steady state yaw response at forward speeds of 36.7 ft/sec (25 mph), 55 ft/sec (37.5 mph), 73.3 ft/sec (50 mph), and 102.7 ft/sec (70 mph) within the envelope defined by Figure II. Within this envelope, the specific vehicle response must be concave downward at all points. Similar response curves obtained with different lateral accelerations shall exhibit the same characteristic shapes.
- In relation to the 0.4 g yaw response curve on Figure II coordinates, as lateral acceleration increases from 0.4 g, the yaw response curve shall progressively move downward; as lateral acceleration decreases from 0.4 g, the yaw response curve shall progressively move upward.
- Provide a steady state yaw response at 73.3 ft/sec (50 mph), and 102.7 ft/sec (70 mph) which shall be within the envelope defined by Figure II at 0.4 g ± 0.02 lateral acceleration for the following combined load and tire inflation pressure conditions:
  1. Vehicle at 100% rated load, and
  2. Front tire inflation pressure at 120% of the design value and rear tire inflation pressure at 80% of the design value.

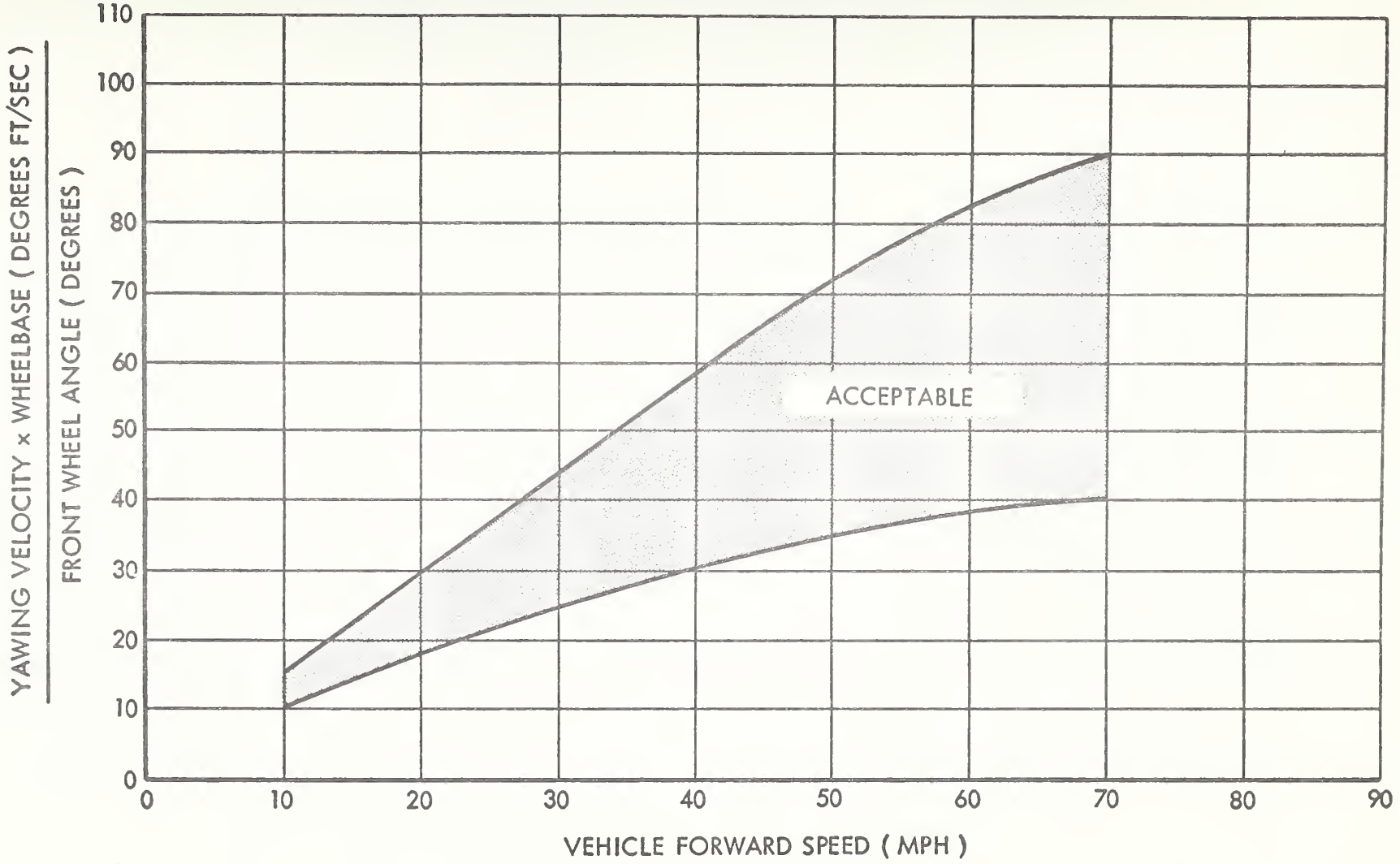


Figure II. RSV Steady State Yaw Response

- With a steering input applied at a rate no less than 500°/sec and held constant at a value which produces 0.4 g steady state lateral acceleration with test speeds of 36.7 ft/sec (25 mph) and 102.7 ft/sec (70 mph), provide a transient yaw response as described by Figure III. In this figure, the upper curve is the upper limit for a test speed of 102.7 ft/sec while the lower curve is the lower limit for a test speed of 36.7 ft/sec (25 mph) and does not apply to the 102.7 ft/sec (70 mph) test. The initial time, T_o, is the time at which one-half the steering input is complete.

Returnability/Feedback

The vehicle shall be driven at 36.7 ft/sec (25 mph) and 73.3 ft/sec (50 mph) around a fixed radius sized to achieve 0.4 g. At a predetermined point on the vehicle path, the driver shall release the wheel completely and the vehicle must meet the following requirements:

- From a test speed of 73.3 ft/sec (50 mph), the yaw rate, 2 seconds after steering wheel release, must be less than 4 degrees per second. From a test speed of 36.7 ft/sec (25 mph), the yaw rate, 2 seconds after steering wheel release, must be less than one degree per second.
- Show steering wheel returnability stability that falls within the envelope defined by Figure IV. In this figure, curve 1 is the upper bound for response with a test speed of 36.7 ft/sec (25 mph); curve 2 is the upper bound for response with a test speed of 73.3 ft/sec (50 mph); and curve 3 is the lower bound for both.

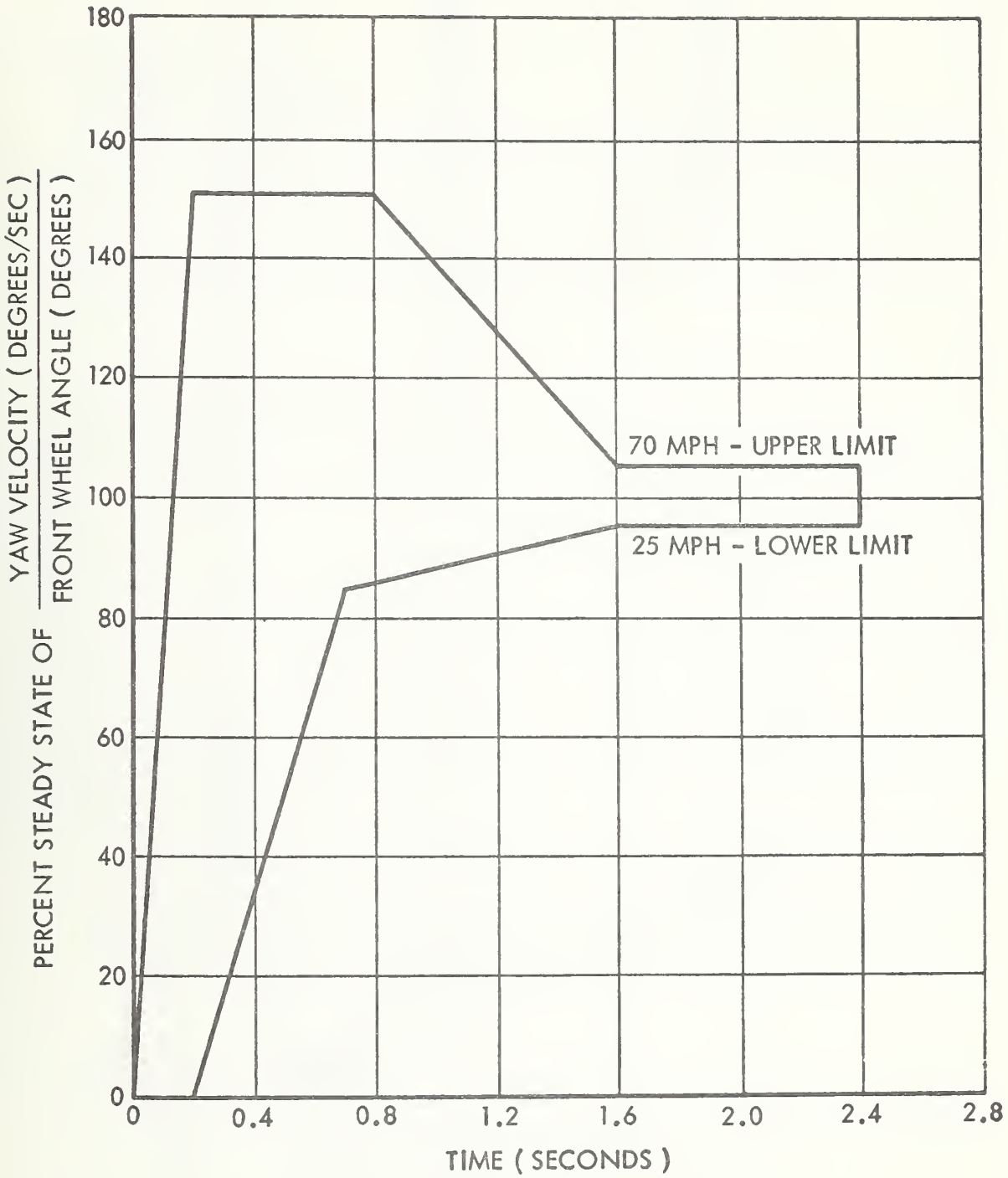


Figure III. RSV Transient Yaw Response versus Time

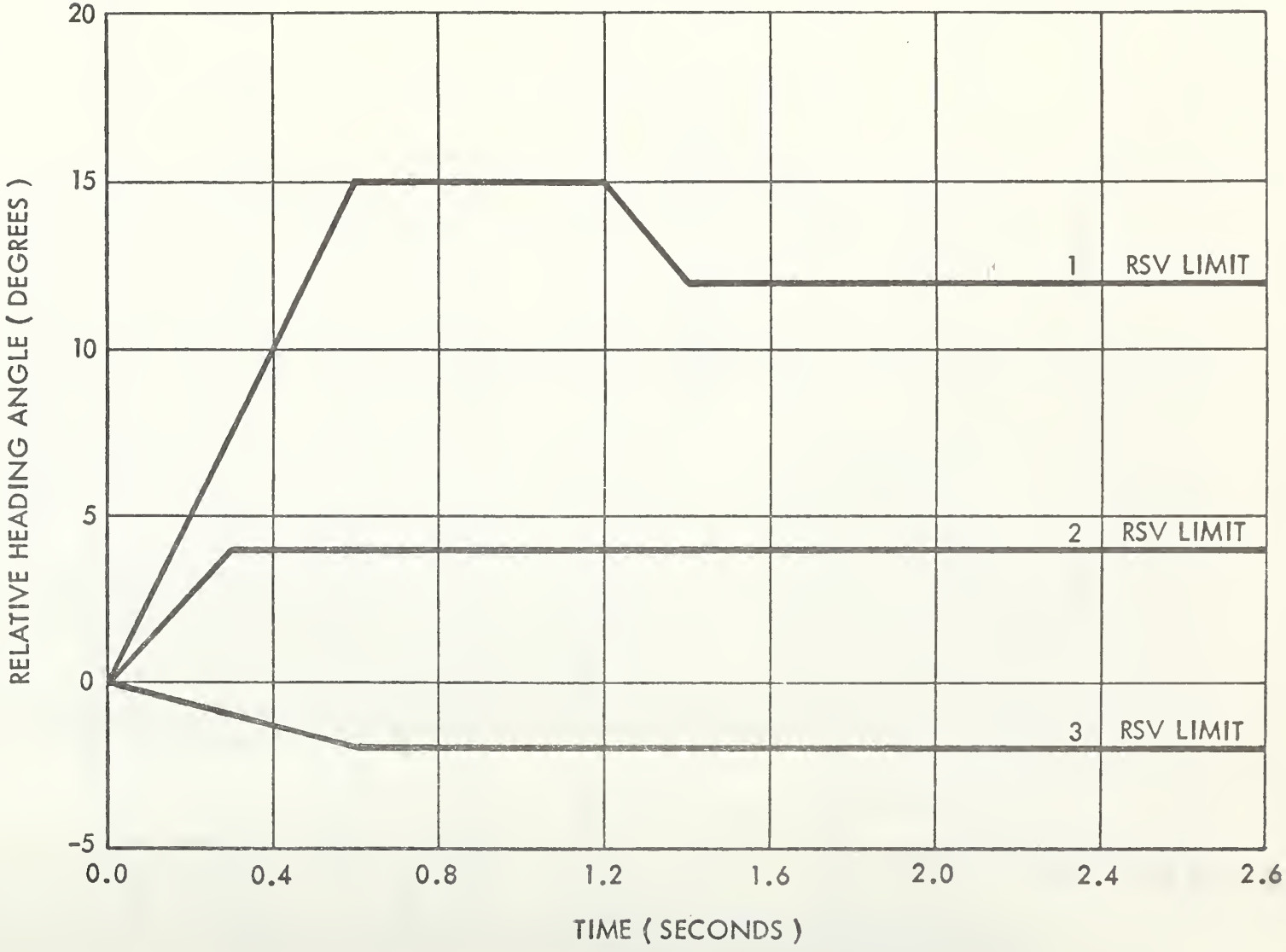


Figure IV. Relative Heading Angles versus Time

2.1.3 Handling

Lateral Acceleration

The vehicle shall, while traveling on a 100-foot radius skid pad at a constant speed, remain stable with lateral accelerations as shown in Table II. A certification circle shall be completed at the required "g" level and a speed tolerance of ± 1 mph with less than 10 degrees total steering wheel movement as the control limit.

Control at Breakaway

The vehicle shall be operated on a skid pad, in a given circular path, at a maximum lateral acceleration until a steady state condition exists. The vehicle speed shall then be gradually increased until any point on the vehicle longitudinal axis within the wheelbase has moved radially outward a distance of 10 feet from the initial path. At this time, the throttle will be closed initiating the test of control at breakaway. Measuring time from the instant the throttle closes, the vehicle must be capable of regaining and following the initial path (plus or minus two feet) within no more than four seconds. This test will be conducted on a steady state circular path of 100 and 225 feet radii.

Other conditions to be adhered to in conducting these tests are:

- No braking shall be performed on the vehicle during recovery.
- Steering wheel movements necessary to regain the original path must not be applied at a rate exceeding 500°/sec.

Directional Stability

This parameter will be verified for the following conditions:

- Crosswind sensitivity
- Steering control sensitivity
- Pavement irregularity

Table II. Lateral Accelerations

SURFACE	TIRE PRESSURE	LATERAL ACCELERATIONS (g)
		FIXED CONTROL
DRY CONCRETE OR ASPHALT	DESIGN VALUE	0.63
	120% DESIGN VALUE	0.62
	80% DESIGN VALUE	0.58
	120% DESIGN FRONT 80% DESIGN REAR	0.65
	80% DESIGN FRONT 120% DESIGN REAR	0.61
WET CONCRETE OR ASPHALT	DESIGN	VALUES TO BE RELATED TO ACTUAL PERFORMANCE ACHIEVED ON DRY SURFACE IN PROPORTION TO WET & DRY TEST SKID NUMBERS.

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	80% DESIGN VALUE	0.58
	120% DESIGN FRONT 80% DESIGN REAR	0.65
	80% DESIGN FRONT 120% DESIGN REAR	0.61
WET CONCRETE OR ASPHALT	DESIGN	VALUES TO BE RELATED TO ACTUAL PERFORMANCE ACHIEVED ON DRY SURFACE IN PROPORTION TO WET & DRY TEST SKID NUMBERS.

Tests for these will be run at 44 ft/sec (30 mph), 73.3 ft/sec (50 mph), 102.7 ft/sec (70 mph), and on level pavement with less than 5 mph head-on or tail winds. Specific requirements for each test are as follows:

a. Crosswind Sensitivity - The vehicle shall be subjected to a step function crosswind application of 73.3 ft/sec (50 mph) plus or minus 7.3 ft/sec (5 mph). Total course deviation for a 20-foot exposure shall be measured two seconds after initiating test and shall be less than the value shown in Figure V for the appropriate distance covered by the vehicle in two seconds.

b. Steering Control Sensitivity - The torque required to cause a yaw rate of 2 degrees per second shall exceed 5 inch pounds applied by a steady force at the rim of the standard wheel. If the vehicle is equipped with power steering, then with the power assist inoperative, the torque required at any speed above 5 mph shall not exceed the "power on" torque, at the same steering condition, by more than a factor of three.

c. Pavement Irregularity Sensitivity - The course shall include a semicylindrical solid ridge of one inch radius lying along a line intersecting the directional vector of the vehicle at an angle of 30 degrees. Total allowable course deviation of the vehicle is one foot measured two seconds after ridge contact at speeds between 30 and 70 mph.

2.1.4 Overturning Immunity

To demonstrate overturning immunity, the vehicle in a minimum load condition (driver only) and in a 100% rated load condition shall not overturn under any combinations of braking and/or steering at any speed on a level paved track. As the minimum, the vehicle must not overturn:

- When negotiating a 1,000 ft slalom course at the maximum steady state speed attainable with pylons spaced at 100 ft intervals. A minimum speed of 50 mph is required.

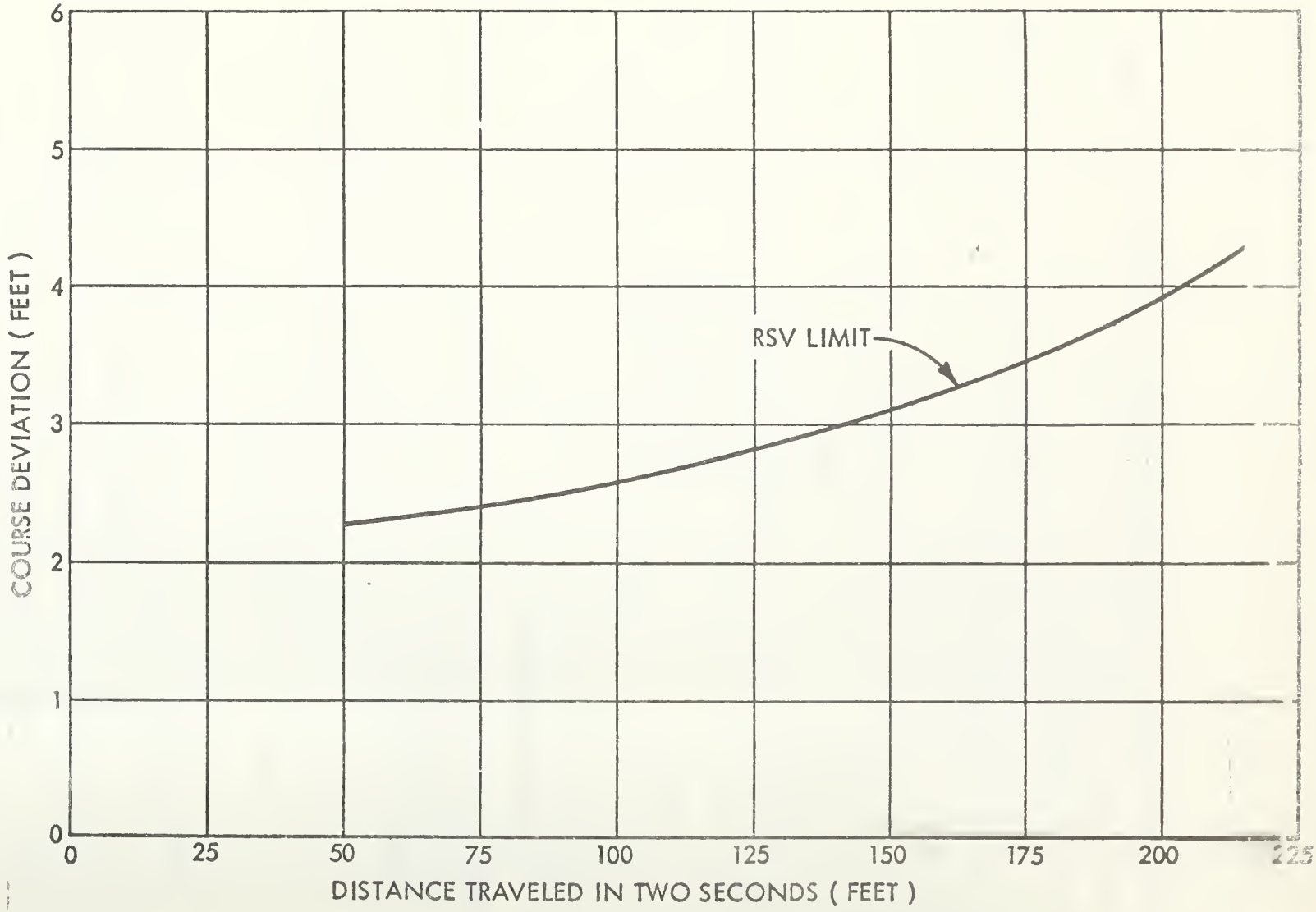

Figure V. Allowable Course Deviation versus Distance Traveled

- When performing the drastic steer and brake* maneuver at initial speeds of 50 and 60 mph.

2.1.5 Power Plant System

The power plant is defined as consisting of a power source which converts duel or energy into mechanical power and a power train which conditions the power and transmits drive torque to the drive wheels and tires. The power plant system shall meet the requirements that follow with the vehicle carrying a payload of 400 lbs.

Acceleration

Adequate power shall be provided to accelerate the vehicle through the velocity ranges and within the times specified below:

0-30 mph in 7 seconds
0-40 mph in 10 seconds
0-60 mph in 20 seconds
30-60 mph in 13 seconds

Power Train

The power train elements and the tires shall be designed to minimize power losses.

Lateral Force Influence

As a minimum, the power output shall remain constant while vehicle travels a 100-foot radius circle at the maximum lateral acceleration under manual control. This performence to be verified for 360° of travel while traveling both clockwise and counterclockwise around the circle.

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*Test procedure for this maneuver is described in, "Vehicle Handling Performance", Vol. I, Highway Safety Research Institute, University of Michigan, November 1972 (DOT HS 800 759).

Fuel Capacity

Sufficient fuel or energy capacity shall be provided for a 250 mile range at a cruising speed of 55 mph.

2.1.6 Ride Performance

The passenger compartment acceleration levels, measured at the seat/passenger interface, shall be below the limits shown in Figure VI, for the indicated range of frequency levels. This performance shall be provided while traveling on:

- Freeways at speeds of 60 to 70 mph
- Rural roads at speeds of 45 to 55 mph
- City roadways at speeds of 25 to 35 mph

2.2 VISIBILITY SYSTEMS

2.2.1 Driver Visibility

The driver's field of view requirements are based upon modifications to published notices of proposed rulemaking: the September 1, 1976, requirements for direct field of view (37 FR 7210) and the January 1, 1974 requirements for indirect visibility (36 FR 1156). The modifications are as follows:

a. Point V_o rather than point M will be used for indirect visibility. If the vehicle is designed to have a very limited range of vision origin points, or a fixed origin point, the point representative of a 50th percentile driver or the single point will replace point V_o for both direct and indirect visibility measurements.

b. In defining zones for direct visibility, all conical surfaces will be replaced by corresponding planar surfaces; e.g., paragraph S 5.8.1 (c) will read "A plane surface containing point V_2 and forming an angle of 11° with the Y plane."

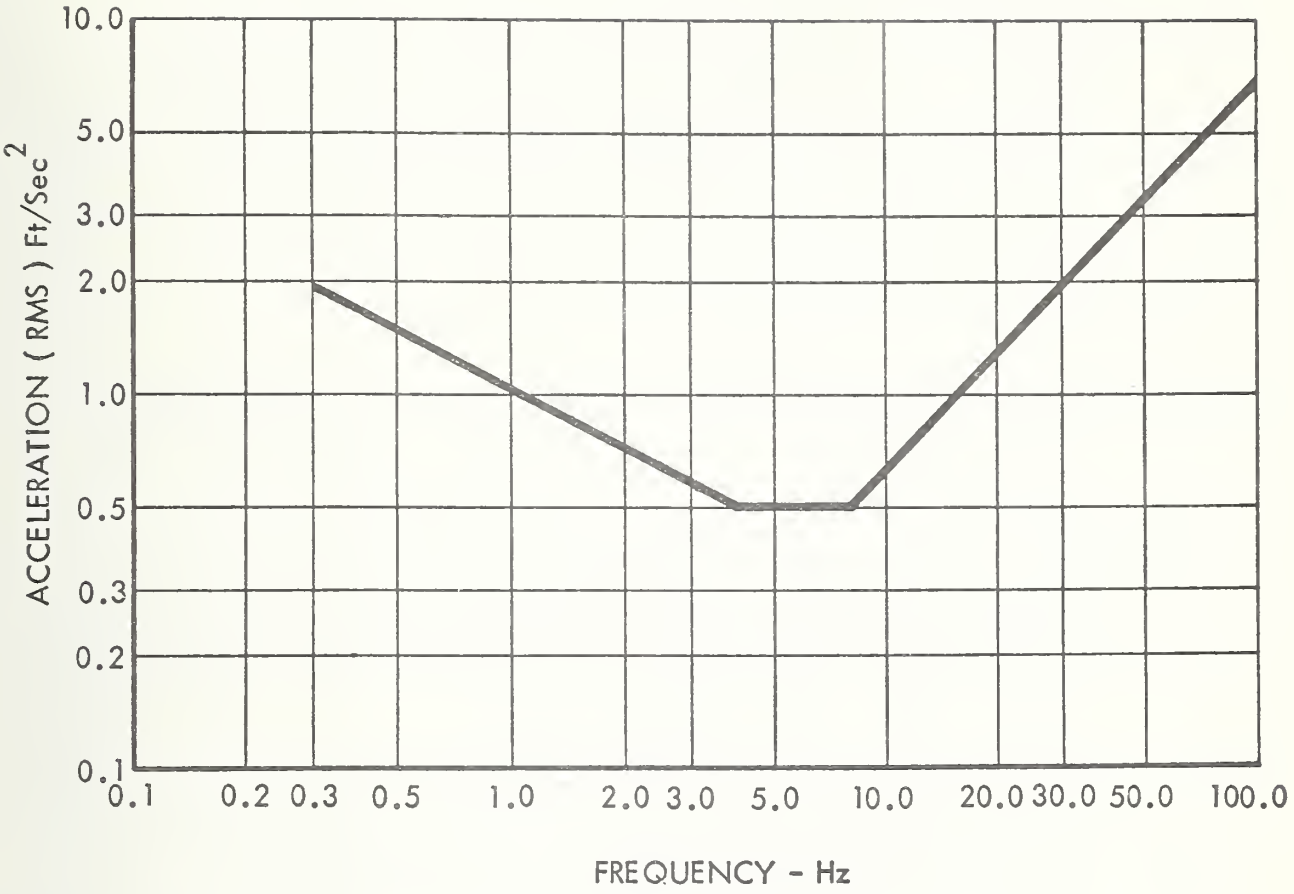

Figure VI. Passenger Compartment Accelerations versus Frequencies

c. Zone I (ref. paragraph S 5.8.1(a) and (b)) is modified from 17° left and right of the X plane to 15° left and right of the X plane. Zones II and III are expanded accordingly.

d. Shade bands if used shall meet the requirements of SAE recommended practice J100.

e. Except for shaded areas, covered above, the luminous transmittance in Zones I through V shall be at least 80% and that in Zone VI shall be at least 70%, as measured per ANS Z26.1, Safety Code for Glazing Materials for Glazing Motor Vehicles Operating on Land Highways.

f. Sun visors are required.

g. The contractor may elect to eliminate corner reference points (ref. paragraph S 7.2) for other safety considerations; e.g., pedestrian safety.

h. Only binocular measurements will be used in determining the obstructed angles in the direct field of view. Binocular or monocular measurements are acceptable for determining target areas visible using indirect systems.

i. The horizontal angular width of obstructions in Zones II and III (ref. paragraph S 9.1(b)) shall not be more than 6° and that of obstructions in Zones IV and V (ref. paragraph S 9.1(c)) shall not be greater than 12°. There shall be no more than four pillars (i.e., two "A" pillars and two "B" pillars excluding vent window pillars) in a 270° arc which is 135° to either side of a line passing through point V_o parallel to the X plane. The steering wheel, windshield wipers and head restraints shall not be considered as obstructions; however, the head restraints shall be designed to provide the minimum obstruction possible consistent with their intended function; e.g., "ring type" or transparent designs.

j. The dimensional criteria for electrical conductors are deleted. The contractor will provide data on the amount of obstruction present.

k. All adjustable indirect visibility devices except the right side mirror, if used, shall be adjustable from the driver's seat. The side mirrors, if used, may be convex; i.e., with a spherical or cylindrical curvature having a single radius of curvature providing 0.5 or greater magnification at the design eye distance. If system design conditions dictate, the contractor may elect to request NHTSA approval for an indirect visibility subsystem using a stepped inside mirror and/or less than 0.5 magnification for the right hand outside mirror.

There shall be a wiper system for the backlight (rear window) designed to clear 75% of the glazing surface within an unobstructed area of Zone VI. The backlight shall be heated for defrosting purposes.

The car shall meet the requirements of FMVSS 107, with requirements within Zones I, II and III of the driver's direct field of view. As a minimum, the windshield defrost/defog subsystem shall meet the requirements of FMVSS 103.

2.2.2 Lighting

As a minimum, the vehicle lighting shall meet the requirements of FMVSS 108 with the proposed or allowed revisions published in 37 FR 22801, and 38 FR 33084.

A three beam headlight system shall be provided having the following forward illumination characteristics:

- Low beam 20,000 candela
- Mid beam 60,000 candela
- High beam 155,000 candela

These beams shall provide the forward illumination patterns shown in Figure VII.

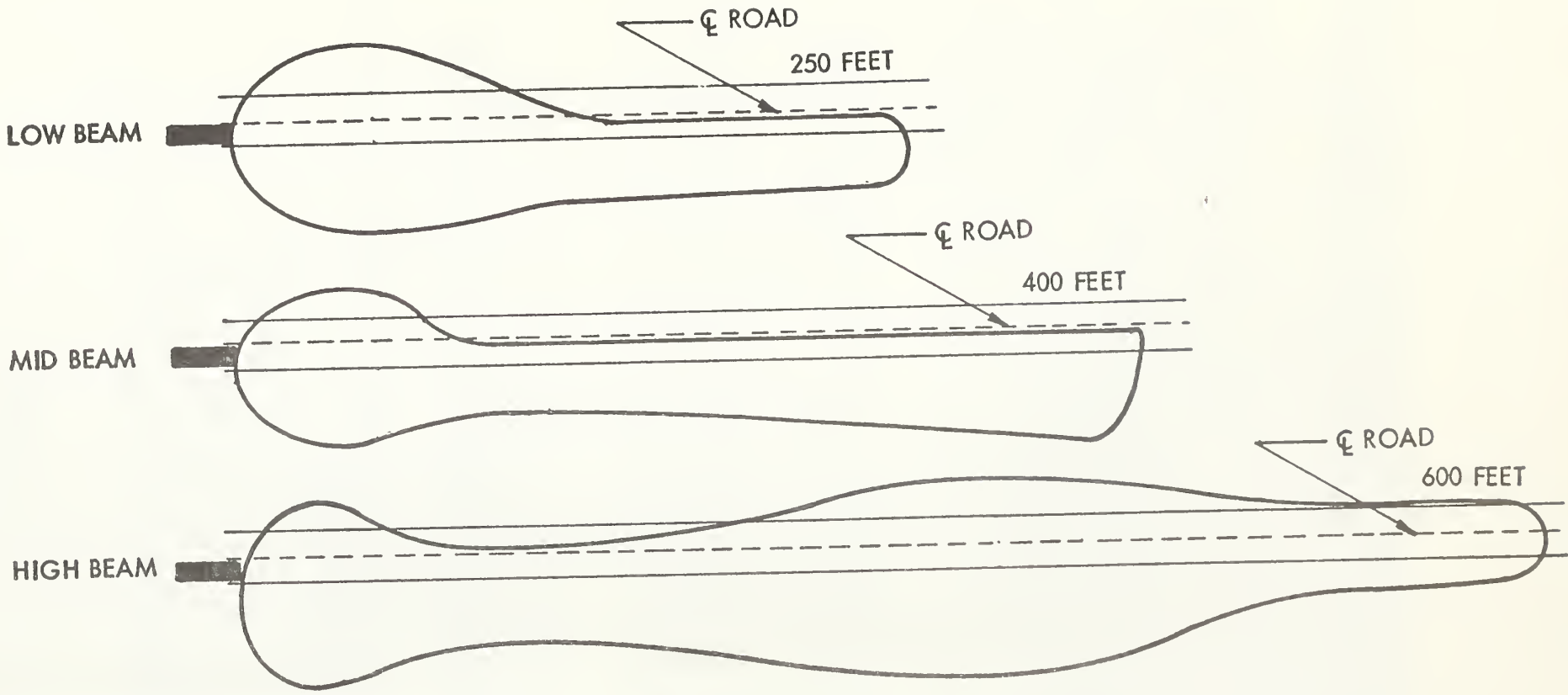

Figure VII. Head Lamp Beam Pattern

The rear lighting system shall be arranged with separate presence, turn and stop signal lamps, additiona turn and stop signal lamps provided for desirable redundancy. A deceleration lamp shall be incorporated to denote vehicle deceleration. The color coding for the designated lamps shall be as follows:

- Stop - red
- Presence - blue or blue-green
- Turn - yellow
- Deceleration - yellow

Front signal lamps shall be provided to indicate turn and presence.

2.3 DRIVER ENVIRONMENT SYSTEMS

2.3.1 Gontrols and Displays

The requirements for controls and displays shall conform with human factors considerations to provide optimum safety in controlling and monitoring the vehicle in all driving situations. The safety to be provided shall, typically, be in the form of early warning of unsafe vehicle conditions, clear and non-ambiguous instrument displays, and minimum potential for unintentional or inadvertent actuation of controls.

The controls and displays shall represent the advanced state of the art in human factors cirteria for vehicle operation and in the control and display devices and instrumentation.

In addition, the controls and displays are to be compatible with crashworthiness and occupant protection requirements stated in this and other sections of the specifications.

The vehicle instrumentation shall be appropriate to the monitoring needs related to safe functioning of the handling and stability, visibility, driver environment, and other vital vehicle systems.

The speedometer and odometer shall conform to SAE J678d containing speed indication to 85 mph and accumulated distance traveled in increments of 0.1 miles. The speed and distance data may be displayed in digital form.

The foot pedals shall prevent inadvertent simultaneous movement of different foot pedals by the same foot, incorporating non-skid characteristics and be suitable for all foot gear; i.e., including heavy overshoes.

The driver's seat and control adjustment shall be adequate to accommodate individuals ranging in size from a 5th percentile female to a 95th percentile male. Means shall be provided for retaining the driver in such a position that he can operate the steering, service brake and throttle controls under resultant accelerations up to 1 g.

2.3.2 Warning Devices

The vehicle shall have a horn satisfying the requirements of SAE J377.

The vehicle shall have a speed warning system audible to the driver which sounds at an activating speed which is adjustable by the driver to any speed from 25 to 85 mph. At 85 mph, the speed warning device will be automatically activated.

Warning lights and/or audible signals to alert the driver to unsafe mechanical and electrical conditions or failures; e.g., engine overheat, low oil pressure, door open, or excessive brake lining wear, shall be provided. These devices shall supplement the display instrumentation to minimize inattentiveness to any instrumentation readings indicating potentially hazardous status.

There shall be a restraint system conditioning monitoring circuit which provides a visible and an audible warning in the event that the system becomes inoperative or improperly used.

2.3.3 Environment

As a minimum, a heating and ventilation system with temperature and vent controls shall be provided.

There shall be a positive pressure in the passenger compartment under all operating conditions. The carbon monoxide concentration shall not exceed 25 ppm when tested per SAE J989.

The air conditioning system, if provided, shall be sized for full occupant capacity and maintain acceptable interior temperature levels under the average range of climatic conditions prevalent in the U.S.

The interior noise levels shall not exceed the decibel (dBA) levels under the following driving conditions:

- Idle 52
- Steady 30 mph 62
- Steady 50 mph 67

2.3.4 Emergency Equipment

Provisions shall be made for readily accessible storage of road emergency equipment. All such equipment shall be securely mounted to the vehicle and not located in any of the crush zones, and if outside of the passenger compartment, shall be on the non-traffic side of the vehicle. Equipment shall include as a minimum:

1. Fire extinguisher
2. Spare electrical fuses (if used)
3. Stopped vehicle warning devices to include:
   - Three flares
   - Red emergency reflective triangle
4. First aid kit
5. Electric lantern

2.4 CRASH ENERGY MANAGEMENT SYSTEMS

The RSV shall be designed to provide structural and occupant protection performance as specified in this section. Structural performance requirements are specified to (1) utilize both the structure and interior occupant protection systems to the extent currently feasible in mitigating forces on occupants in the vehicle in all specified crash modes; (2) provide

a safe environment for struck vehicles (i.e., low aggressiveness) in collisions with the RSV; (3) provide protection against damage in low speed crashes; and (4) provide a "low hostility" environment in pedestrian and cyclist crashes. Performance requirements for each of these conditions are established in this section as a best estimate of desired vehicle capability considering the current state of the art in crashworthiness design, preliminary evaluation of weight and cost effectiveness practicality, and design achievability. It is anticipated that refinements to this Phase I evaluation will be made in Phase II as RSV design data becomes available, and the vehicle structural and restraint configurations and performance characteristics are more accurately defined.

To cimplify the specification of performance in this section, all accelerations and decelerations are stated as accelerations; also, all impact velocities, whether forward or rearward, and whether pre-crash or imparted, are stated as velocities.

2.4.1 Structural Systems

The structural systems identified in this specification are basically the primary impact areas. This breakout assumes that related structure such as the floor, for example, will be functionally integrated into the overall structure to complete the vehicle. The primary structural systems are:

a. Front structure
b. Side structure
c. Roof structure
d. Rear structure

These structural systems, in addition to serving as primary impact areas, when combined with the floor and other sub-structures, form the passenger compartment. Regardless of the direction of impact, the passenger compartment and its occupants must be protected from excessive intrusion, and acceleration.

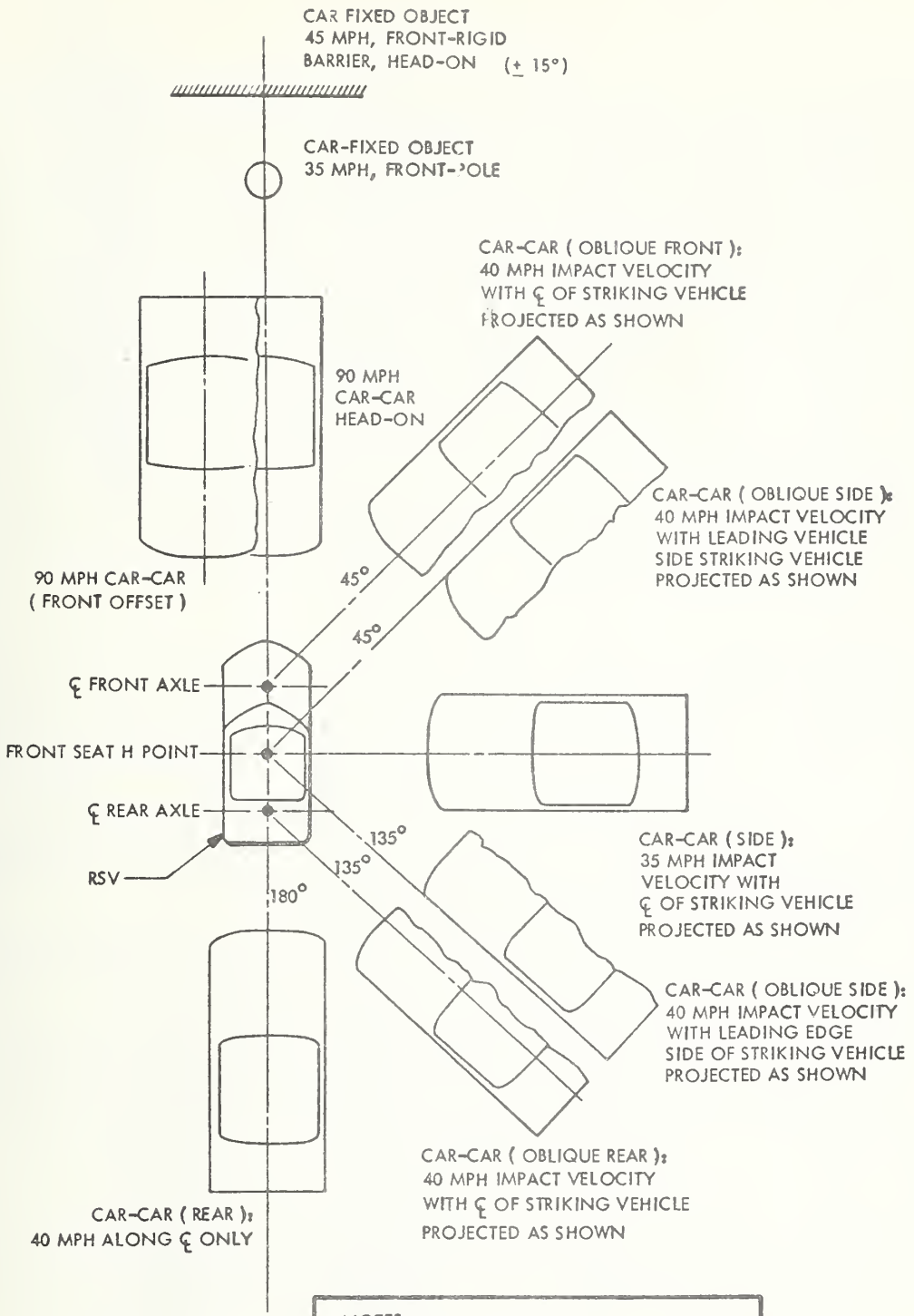

Figure VIII Design Crash Modes

Minimum passenger compartment intrusion consistent with optimized performance and weight is desired. In the absence of technical justification, residual intrusion greater than three inches from the normal inside surface to which the padding or lining is attached will not be permissible. When greater intrusion is allowed, it shall be shown (1) that an increase in intrusion will not significantly increase the probability of entrapment, serious injury or death to the occupants, (2) that the intrusion will be controlled, and (3) that the intrusion can be limited to the approximate values and areas proposed.

The occupant protection requirements given in Section 2.5.2 are applicable for all design crash modes defined in Figure VIII.

2.4.1.1 Front Structure

Figure IX graphically depicts the allowable dynamic crush characteristics for the front structure of the RSV and its opposing vehicle (5000 lb vehicle) for compatibility in the vehicle-vehicle collision modes defined in Figure VIII. Single excursions in the dynamic load (or associated passenger compartment accelerations) of up to five milliseconds duration above the boundary given in Figure IX are permissible.

The lateral crush load of the front structure will be limited to 60 kips to be compatible with the RSV in a side-swipe configuration.

The front structure shall be designed to provide performance in front-to-side crashes in accordance with the paragraph on side structure and in front-to-rear crashes in accordance with the paragraph on rear structure.

Provisions shall be made for a 4 inch damage "free" stroke of the front bumper (and/or front structure) with a maximum acceleration of 5 g's.

The front and rear bumpers shall provide protection against underride/override when loaded to 50% of the rated load from a height of 10 inches to 16-1/2 inches during either maximum acceleration or panic braking

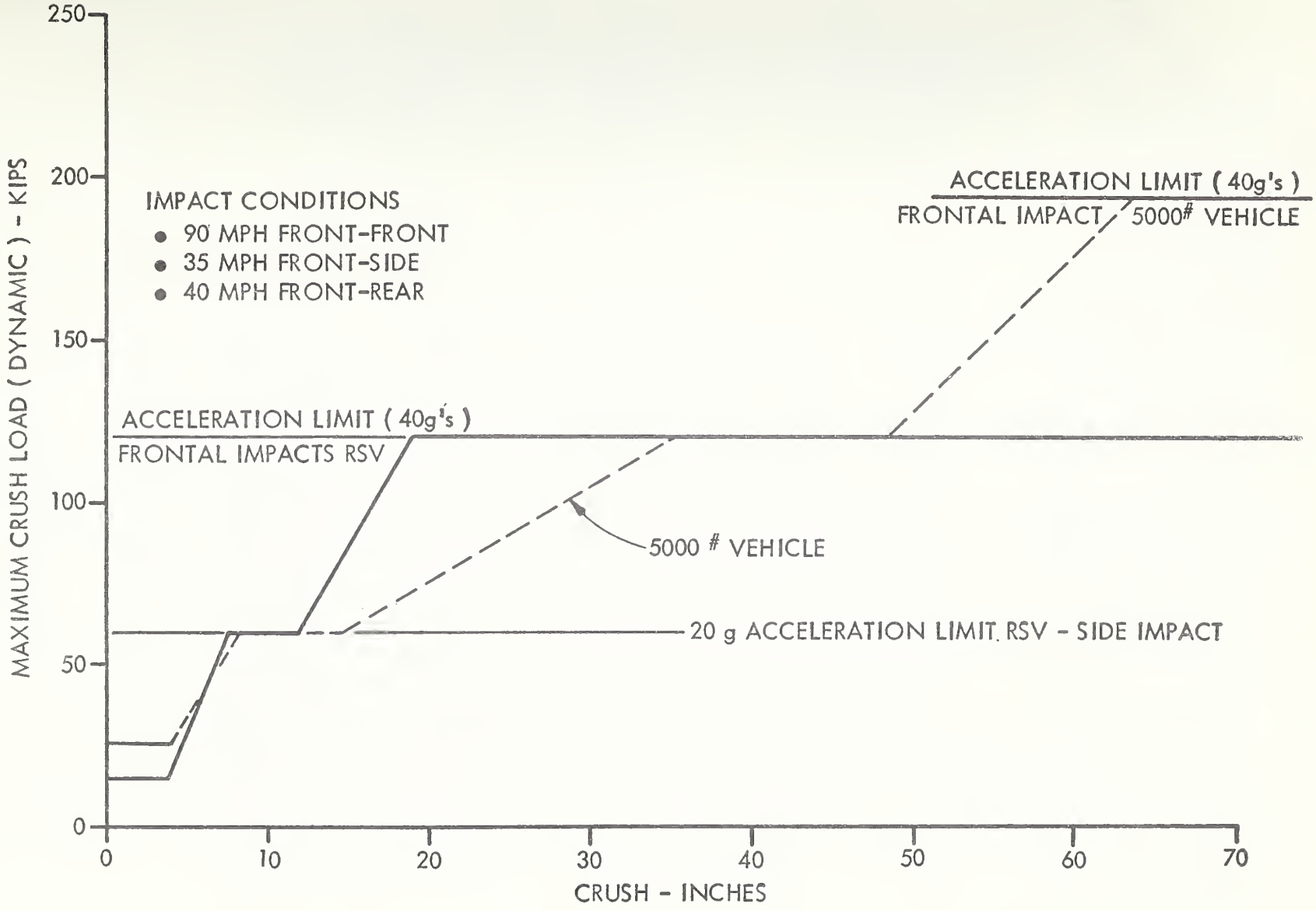

Figure IX . Front End Stiffness Characteristics for Vehicle-Vehicle Compatibility

The profile of the vehicle front end shall be such that no "hard" structures (e.g., hood, grill, and associated back-up structure) can make contact with the impacted vehicle side structure above the belt line during impact. If such contact is unavoidable, the striking surfaces shall be designed to deform away from the side structure without imparting severe damage and resulting passenger compartment intrusion.

2.4.1.2 Side Structure

The side structure/door system shall be designed for side collisions to 59 ft/sec (40 mph) when struck under the conditions shown in Figure VIII by a vehicle weighing 5000 lbs with front structure longitudinal performance specified in Figure IX, and lateral characteristics compatible with the RSV side structure (60 kips maximum crush load).

2.4.1.3 Roof Structure

The roof structure shall be capable of demonstrating satisfactory rollover performance by testing a dolly-mounted vehicle which is rolled from a dolly at a velocity of 30 mph in accordance with the rollover test described in FMVSS 208.

2.4.1.4 Rear Structure

Rear-end crash modes are given in Figure VIII. Compatibility with the front structure specified in the paragraphs on front structure shall be provided.

The bumper shall provide protection against underride/override when loaded to 50% of rated load from a height of 10 inches to 16-1/2 inches during either maximum acceleration or panic braking.

2.4.2 Exterior Protection

To the maximum extent consistent with the requirements of the specifications for crashworthiness for reduction in highway injuries or fatalities, the vehicle shall be designed so as to reduce or eliminate body damage vulnerability in low speed collisions.

As a minimum, both front and rear exterior protection systems shall be capable of sustaining pendulum collision tests of 5 mph as well as barrier collision tests of 5 mph with the vehicle's power plant operating and the power train in neutral position without producing any vehicle body, suspension, or power train damage. The pendulum and barrier collision tests shall be as specified in FMVSS 208.

2.4.3 Fuel System Integrity

No penetration of the fuel tank(s) or energy source and connecting lines or release of fuel from these components shall be permitted under all test conditions described within this specification. Release of fuel from the power plant shall be limited to the minimum amount practicable for the plant design.

2.4.4 Pedestrian/Cyclist Protection

2.4.4.1 Vehicle Design Requirements

Exterior Geometry. In the absence of technical justification to the contrary, the exterior geometry of the vehicle shall conform to the following descriptions:

a. The front surface of the vehicle is defined as that portion of the vehicle skin (excluding the bumper) forward of the leading edge of the windshield. The rear surface of the vehicle is defined as that portion of the vehicle skin (excluding the bumper) rearward of the trailing edge of the backlight. The front and rear surfaces of the vehicle shall have the following geometry.

- The intersection of the front or rear surface and any intersecting horizontal plane shall describe a convex curve with the apex lying on the vehicle centerline.
- The intersection of the front or rear surface and any intersecting vertical plane which is parallel to the longitudinal axis of the vehicle shall describe a convex curve. The extreme forward or rearward point (as appropriate) of the curve shall be located at the lowest extremity of the vehicle front or rear surface (as appropriate).
- The vehicle skin adjacent to each wheel well shall be contoured as required to preclude protrusion of any portion of the wheel/tire beyond an imaginary surface bounded by the rim of the wheel well opening. In the case of the front wheels, this requirement applies only when the wheels are in a zero yaw position.

b. The side surfaces are defined as those portions of the vehicle skin and glazing that are located between the leading edge of the windhsield and the trailing edge of the backlight and lie in a general vertical plane parallel to the longitudinal axis of the vehicle. The side surfaces shall have the following geometry.

- The intersection of a side surface and any intersecting vertical planp which is perpendicular to the longitudinal axis of the vehicle shall describe a convex curve with the extreme outboard point located at the lowest extremity of the vehicle side surface. This requirement does not necessarily include the side glazing.
- The geometry of all side glazing and the design of any adjustable side glazing shall preclude protrusions of any

portion of the side glazing beyond an imaginary surface bounded by the adjacent vehicle skin.

c. All bumper faces shall be vertical and shall have a vertical dimension of at least 8 inches.

d. If wheel covers are used, the wheel covers shall have a convex shape and its surface shall be free of sharp protrusions.

Exterior Finish. The finish applied to the vehicle skin, bumpers and wheel covers shall contain no abrasive or frictional materials except as may be required to enhance the control of pedestrian/cyclist dynamics during and/or after impact.

Exterior Protrusions. Exterior vehicle protrusions, other than those provides expressly for pedestrian safety, shall be eliminated or recessed to the maximum extent feasible. Protrusions other than those provided expressly for pedestrian safety which cannot be eliminated or recessed shall be designed to crush or break away when contacted from any direction if (a) a pressure of 80 psi is exceeded, or (b) a pressure of 50 psi is maintained for a period of more than 5 milliseconds.

All exposed bumper surfaces shall be covered with energy absorbing material. The amount and characteristics of the material used shall be commensurate with minimizing pedestrian injuries.

Visibility. No requirements exist beyond those specified in paragraph 2.2.1 of this specification.

Audio/Visual Signaling. A driver-operated audible signaling device shall be provided as specified in paragraph 2.3.2 of this specification.

No visual signaling devices are required other than those specified in paragraph 2.2.2 of this specification.

2.4.4.2 Vehicle Design Goals

Provisions should be made to control the trajectory of pedestrians or cyclists who are impacted by the front of the vehicle at velocities above 10 mph. In this situation, the pedestrian/cyclist should be (1) propelled onto the vehicle hood if initial contact is between the inner edges of the front tires (in zero yaw position), and (2) propelled out of the vehicle path if initial contact is outboard of the inner edge of either front tire (in zero yaw position).

In conjunction with the above paragraphs, the vehicle hood design should incorporate injury attenuating energy absorption where feasible and shall be free of sharp protruding edges and narrow hard surfaces that can inflict piercing or cutting injuries to the victim while in contact with the vehicle.

2.5 OCCUPANT COMPARTMENT SYSTEMS

2.5.1 Seating Systems

The front and rear seating systems shall be designed to provide reasonable occupant protection under all crash modes described in Figure VIII. The seating system shall be functionally integrated with occupant restraint system performance.

During rear vehicle impact, the seats shall provide adequate head, back and whole body restraint to retain the occupant, prevent hyperextension of the neck, and assure that tolerable occupant accelerations and local loadings are not exceeded. Rearward translation and deflection of the front seats shall be limited to the extent necessary to prevent imparting injury-producing loads on rear seat occupants and to assure retention of front seat occupants.

In frontal vehicle impacts, the seat systems shall not impose injury-producing forward loads on the occupants during or after deceleration of his forward motion. The seat system shall provide adequate impact

attenuation to prevent exceeding human tolerance levels on occupant loading resulting from any rebound phase of the occupant restraint system.

In angular and lateral vehicle impacts, the seat system shall be integrated with door padding, consoles and other interior components to limit loading of the occupants to tolerable levels. The seat systems shall also limit vertical loading on the occupants to tolerable levels during all operating and crash conditions under which they are contacted by the occupant.

The seat and head restraints shall satisfy all requirements of FMVSS 201 and 202 as a minimum. For unique head restraint designs which make compliance with the specified test conditions of the FMVSS 202 technically inappropriate, the system must, under the conditions of maximum forward vehicle acceleration resulting from prescribed vehicle design conditions of Section 2.4, restrict head rotation relative to upper torso to angles not exceeding 60° and head impact conditions to values not exceeding head injury criteria value of 1000 as defined in FMVSS 208. In general, the seating system shall satisfy the requirements specified in Table III.

Table III

SPECIFICATION FOR RSV SEATING SYSTEM

Specification	Requirement
Rear impact speed*	40 mph
Head acceleration (P-A)	HIC 1000
Chest force (P-A)	60 g/3 msec
Head rotation	60°

*car-to-car

2.5.2 Occupant Restraint Systems

Load distributions on various portions of the body are known to be critical parameters influencing serious occupant injury and survival. Human tolerance to localized loading (in terms of load per unit area) is not currently adequately defined. It is therefore a goal in this program to utilize practical means to minimize local load applications to the body.

To the extent practical, all controls and interior protrusions shall be recessed or shielded making them noncontactable by an occupant whether restrained or not. Where this is not practical, all contactable interior protrusions shall be frangible, crushable or have breakaway properties. All other interior surfaces shall minimize local forces on the occupants. A design goal shall be that no more than 50 psi contact pressure shall be developed for more than five milliseconds between any interior surface or prortrusion and a colliding occupant for all directions and magnitudes of crash modes specified in this document. Short-time peaks in pressure greater than 50 psi, but not to exceed 80 psi, will be allowed for periods not to exceed five milliseconds.

Vehicle interior surfaces which are contactable by the face of an occupant during crash shall be designed to provide no greater than a 200 pound resistance to penetration of a 6-1/2 inch diameter rigid head form weighing 11.5 pounds during dynamic impact of the crash condition until a one inch penetration has been exceeded. During the initial one inch penetration of the head form, at least 50 inch pounds of energy shall be absorbed. Transparent glazing shall not be subject to these requirements at this time.

For all directions and magnitudes of crash tests specified herein, the additional injury criteria (a) through (e) shall not be exceeded.

(a) All portions of the test device shall be retained within the vehicle passenger compartment throughout the test.

(b) The resultant acceleration at the center of gravity of the head shall not exceed a head injury criteria level of 1000 calculated by the method described in FMVSS 208.

(c) The resultant acceleration at the center of gravity of the upper thorax shall not exceed 60 g, except for intervals whose cumulative duration is not more than three milliseconds. Additional restrictions on the acceleration magnitude along the orthogonal axes shall be: A-P acceleration shall not exceed 60 g for periods exceeding three milliseconds duration; S-I acceleration shall not exceed 20 g for periods exceeding three milliseconds; laterla acceleration shall not exceed 30 g for periods exceeding three milliseconds.

(d) The force transmitted axially through each upper leg shall not exceed 1700 pounds.

(e) Rearward angular displacement of the head reference line shall be limited to 60° from the torso reference line under the specified vehicle rear impact conditions in Figure VIII.

An onset rate of 1500 g per second or less shall be a design goal for the occupant chest when the following conditions exist:

1. A change in g level up to 20 g occurs, and
2. When upper g level is sustained for a period up to 10 milliseconds.

Occupant protection systems shall be selected on the basis of the relative cost benefit merits of alternative systems. For an occupant protection system which includes a functional mechanism for crashes above a specific speed, requirements of (a) through (d) above shall be satisfied at crash speeds 5 mph higher than the predetermined speed without benefit of the mechanism of device as well as at impact speeds at 5 mph lower than the predetermined speed.

2.5.3 Flammability

The energy, electrical and exhaust systems shall be designed to assure containment of fuel or corrosive liquids in a variety of crash modes or vehicle attitudes, as well as the exclusion of volatile materials coming in contact with potential ignition sources. Interaction of the structure when deformed or when scraped on road surface must not affect the fuel or energy system by causing excessive spillage or ignition of flammable liquids or gases by sparks of a scraping structure or electrical discharges.

Interior materials that will not support combustion, will not melt, and will not emit tocix fumes when exposed to flame or high temperatures shall be used to the extent practical. The flammability requirements of FMVSS 302 shall be met.

A small fire extinguisher (not to exceed 2.5 pounds in weight) shall be provided in the occupant compartment of the vehicle. The extinguishing agent should be rated for small Class A, Class B and Class C fires, and when used under fire conditions, should not have severe or prolonged harmful effect on humans. The extinguisher shall be readily available for the driver and front seat occupant, easily recharged, easily inspected and inexpensive.

2.5.4 Interior Design

The interior occupant compartment design shall satisfy FMVSS 201 as a minimum. The restrained occupant shall be provided with adequate stroking distance during the frontal crash modes defined in Figure VIII to minimize contact with the vehicle interior. For side impacts, as specified in Figure VIII, the occupant/interior impact force shall not exceed the human tolerance limits specified in paragraph 2.5.2. The steering control system shall satisfy the impact requirements in FMVSS 203 and 204.

2.5.5 Emergency Egress

Consideration shall be given to providing the RSV for provisions for occupant escape or rescue from the passenger compartment in any attitude it may have as a result of collision, rollover, or submersion. Geometry and space availability to accommodate the large variations in age and size of occupants and the operational features of any latch and release mechanism to be used under adverse conditions of injury, panic, darkness, and unusual vehicle orientations must be considered.

3.0 VEHICLE SYSTEMS REQUIREMENTS

The major portion of the preceding RSV specifications are directed toward those systems whose performance is vital to safety in the projected usage and accident environment. The remaining vehicle systems, directly and indirectly safety related, shall be equivalent to the state of the art projected for production vehicles in 1985. The vehicle systems shall be designed to withstand normal service conditions and/or loads encountered throughout their normal life without failure. No unusual maintenance or servicing actions shall be required and routine replacement items (e.g., tires, batteries) shall be readily available to the consumer.

It is anticipated that the life of the 1985 production vehicle will be extended beyond the present 10 year life expectancy to possibly 15 years in order to conserve the energy and material resources required to produce and operate automobiles. The life factor shall be a design consideration.

3.1 POWER PLANT, FUEL, COOLING AND EXHAUST SYSTEMS

The power plant, fuel and exhaust systems shall meet all requirements for control of air pollution for new motor vehicles and new motor vehicle power plants as specified in the Federal Register, Vol. 37, No. 221 and any subsequent updating thereto relating to the mid-80's. The standards used for RSV exhaust emissions shall be the same as for the production

vehicle requirements for the 1985 period of vehicle manufacture. Tests shall be conducted to obtain emission data on one vehicle; no emission durability tests will be conducted.

The power plant cooling systems shall be designed to perform in accordance with normal automotive standards. Engine coolants shall comply with SAE J814 and system materials shall provide for satisfactory service life.

The exhaust system shall be designed in accordance with standard automotive practice and shall be fabricated from materials which provide acceptable service life.

3.2 TIRE AND WHEEL SYSTEMS

The tires and wheels selected for the RSV shall meet the requirements of FMVSS 109 and 110.

If runflat devices are used in the vehicle tires, the vehicle with 100% rated load and single tire deflation on either the front or rear wheel on the driver's side shall have:

- A minimum of 3-1/2 inches of ground clearance, and
- A range capability of 100 miles of travel at 50 mph.

3.3 ELECTRICAL SYSTEM

The electrical system shall be designed to accommodate all normal operating loads (ignition, lighting, brakes, instrumentation warning systems, etc.) and normally utilized accessories. Wiring harnesses, fuses, alternator/generator and storage battery shall be sized with sufficient margin to provide economical and low maintenance operation over the life of the vehicle.

3.4 INTERIOR COMFORT

Provisions shall be made for driver and passenger comfort in accordance with conventional automotive practice. These shall include fresh air ventilation, courtesy lighting, radio and clock. The passenger compartment shall be thermally insulated to minimize interior temperature fluctuations arising from both vehicle and exterior heat sources; acoustical insulation shall be provided to reduce interior noise arising from both vehicle and exterior noises. Interior storage shall be provided in the form of glove compartments, map pockets, etc.

3.5 MAINTENANCE

All vehicle systems shall be designed to withstand service conditions or loads throughout the life of a normal production vehicle. In all systems, ease and economy of maintenance as well as safety of maintenance operations shall be considered.

Provisions shall be provided for plug-in with any standardized automotive diagnostic system(s) that may be implemented in the mid-80's.

4.0 PRODUCIBILITY

In addition to meeting the safety and functional performance requirements set forth in the preceding sections of this specification, the design and production of the RSV shall reflect the resources, technology, and markets projected for the industry in the mid-80's. The producibility requirements associated with these considerations follow; an annual production rate of 500,000 units is projected for the vehicle class represented by the RSV.

4.1 MATERIALS AND APPLICATIONS

The materials and fabrication and assembly processes required by the production designs of the vehicle shall be in accordance with the technology and design trends projected into the mid-80's. Significant

departures from currently projected technology or trends in any of these areas shall be justified in terms of automotive industry acceptance criteria (lead times, capital investments, costs, etc.), the impact on energy and material resources, economic factors, and other related producibility considerations.

4.2 COMPONENTS AND SUBSYSTEMS

The functional elements of the vehicle (power system, brakes, suspension, lighting, etc.) shall represent production designs commensurate with the advances projected for these elements in the mid-80's.

4.3 PROTOTYPE RSV

A prototype RSV is defined as the experimental vehicle(s) manufactured, in advance of its intended production time frame, for test and demonstration purposes. Accordingly, proprietary data restrictions, development and/or manufacturing costs, or limited material or product availability may preclude the prototype RSV designs and manufacture from complying with production design specifications. For these areas where such constraints exist, the specific design, material, or product which would provide compliance shall be identified. An alternative design, material, or product shall be proposed as a replacement for use in the prototype RSV, and submitted for DOT approval. The selection of the alternative(s) shall be supported by appropriate studies. The estimated deviation(s) from performance specifications resulting from the use of the proposed alternative(s) shall be defined.

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